



National Aeronautics and Space Administration

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## **AERONAUTICAL ENGINEERING**

### A CONTINUING BIBLIOGRAPHY WITH INDEXES

(Supplement 230)

A selection of annotated references to unclassified reports and journal articles that were introduced into the NASA scientific and technical information system and announced in August 1988 in

- Scientific and Technical Aerospace Reports (STAR)
- · International Aerospace Abstracts (IAA).





#### INTRODUCTION

This issue of Aeronautical Engineering -- A Continuing Bibliography (NASA SP-7037) lists 563 reports, journal articles and other documents originally announced in August 1988 in Scientific and Technical Aerospace Reports (STAR) or in International Aerospace Abstracts (IAA).

The coverage includes documents on the engineering and theoretical aspects of design, construction, evaluation, testing, operation, and performance of aircraft (including aircraft engines) and associated components, equipment, and systems. It also includes research and development in aerodynamics, aeronautics, and ground support equipment for aeronautical vehicles.

Each entry in the bibliography consists of a standard bibliographic citation accompanied in most cases by an abstract. The listing of the entries is arranged by the first nine *STAR* specific categories and the remaining *STAR* major categories. This arrangement offers the user the most advantageous breakdown for individual objectives. The citations include the original accession numbers from the respective announcement journals. The *IAA* items will precede the *STAR* items within each category

Seven indexes -- subject, personal author, corporate source, foreign technology, contract number, report number, and accession number -- are included.

An annual cummulative index will be published.

Information on the availability of cited publications including addresses of organizations and NTIS price schedules is located at the back of this bibliography.

## **TABLE OF CONTENTS**

		Page
Category 01	Aeronautics (General)	473
Includes a	Aerodynamics aerodynamics of bodies, combinations, wings, rotors, and control surd internal flow in ducts and turbomachinery.	477
	Air Transportation and Safety bassenger and cargo air transport operations; and aircraft accidents.	501
includes o	Aircraft Communications and Navigation digital and voice communication with aircraft; air navigation systems and ground based); and air traffic control.	502
Category 05 Includes a	Aircraft Design, Testing and Performance aircraft simulation technology.	507
~ ,	Aircraft Instrumentation cockpit and cabin display devices; and flight instruments.	518
Includes p	Aircraft Propulsion and Power brime propulsion systems and systems components, e.g., gas turbine and compressors; and onboard auxiliary power plants for aircraft.	522
	Aircraft Stability and Control ircraft handling qualities; piloting; flight controls; and autopilots.	526
includes a	Research and Support Facilities (Air)  irports, hangars and runways; aircraft repair and overhaul facilities;  els; shock tubes; and aircraft engine test stands.	530
Includes a facilities (s space con spacecraft	Astronautics astrodynamics; ground support systems and space); launch vehicles and space vehicles; space transportation; nmunications, spacecraft communications, command and tracking; design, testing and performance; spacecraft instrumentation; and propulsion and power.	540
Includes cl physical cl	Chemistry and Materials hemistry and materials (general); composite materials; inorganic and hemistry; metallic materials; nonmetallic materials; propellants and materials processing.	540

Category 12 Engineering Includes engineering (general); communications and radar; electronics and electrical engineering; fluid mechanics and heat transfer; instrumentation and photography; lasers and masers; mechanical engineering; quality assurance and reliability; and structural mechanics.	543	
Category 13 Geosciences Includes geosciences (general); earth resources and remote sensing; energy production and conversion; environment pollution; geophysics; meteorology and climatology; and oceanography.	552	
Category 14 Life Sciences Includes life sciences (general); aerospace medicine; behavioral sciences; man/system technology and life support; and space biology.	N.A.	
Category 15 Mathematical and Computer Sciences Includes mathematical and computer sciences (general); computer operations and hardware; computer programming and software; computer systems; cybernetics; numerical analysis; statistics and probability; systems analysis; and theoretical mathematics.	553	
Category 16 Physics Includes physics (general); acoustics; atomic and molecular physics; nuclear and high-energy physics; optics; plasma physics; solid-state physics; and thermodynamics and statistical physics.	554	
Category 17 Social Sciences Includes social sciences (general); administration and management; documentation and information science; economics and cost analysis; law, political science, and space policy; and urban technology and transportation.	557	
Category 18 Space Sciences Includes space sciences (general); astronomy; astrophysics; lunar and planet- ary exploration; solar physics; and space radiation.	N.A.	
Category 19 General	557	
Subject Index	A-1	
Personal Author Index		
Corporate Source Index		
Foreign Technology Index	D-1	
Contract Number Index		
Report Number Index Accession Number Index		
ACCESSION NUMBER Muex	🕶 .	

## TYPICAL REPORT CITATION AND ABSTRACT

NASA SPONSORED

ON MICROFICHE ACCESSION NUMBER -► N88-10026\*# National Aeronautics and Space Administration. --- CORPORATE SOURCE Ames Research Center, Moffett Field, Calif. - HIMAT FLIGHT PROGRAM: TEST RESULTS AND PROGRAM TITLE-ASSESSMENT OVERVIEW AUTHORS-DWAIN A. DEETS, V. MICHAEL DEANGELIS, and DAVID P. LUX **PUBLICATION DATE -**→ Jun. 1986 30 p REPORT NUMBERS NASA-TM-86725; H-1283; NAS 1.15:86725) Avail: NTIS HC **AVAILABILITY SOURCE** PRICE CODE-A03/MF A01 CSCL 01C - COSATI CODE The Highly Manueverable Aircraft Technology (HiMAT) program consisted of design, fabrication of two subscale remotely piloted research vehicles (RPRVs), and flight test. This technical memorandum describes the vehicles and test approach. An overview of the flight test results and comparisons with the design predictions are presented. These comparisons are made on a single-discipline basis, so that aerodynamics, structures, flight controls, and propulsion controls are examined one by one. The interactions between the disciplines are then examined, with the conclusions that the integration of the various technologies contributed to total vehicle performance gains. An assessment is made of the subscale RPRV approach from the standpoint of research data quality and quantity, unmanned effects as compared with manned vehicles, complexity, and cost. It is concluded that the RPRV technique, as adopted in this program, resulted in a more complex and costly vehicle than expected but is reasonable when compared with alternate ways of obtaining comparable results

## TYPICAL JOURNAL ARTICLE CITATION AND ABSTRACT

ON MICROFICHE

ACCESSION NUMBER **→** A88-10095#

→ SYNTHESES OF REDUCED-ORDER CONTROLLERS FOR TITLE -

ACTIVE FLUTTER SUPPRESSION AUTHORS-

ATSUSHI FUJIMORI and HIROBUMI OHTA Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. Japan Society for --JOURNAL TITLE 35, no. 402, 1987, p. 353-362. In Japanese, with abstract in English. refs

Reduced-order controllers for active flutter suppression of a two-dimensional airfoil are studied using two design approaches. One is based on the generalized Hessenberg representation (GHR) in the time domain, and the other, called the Nyquist frequency approximation (NFA), is a method in the frequency domain. In the NFA method, the reduced-order controllers are designed so that the stability margin of the Nyquist plot may be increased over a specific frequency range. To illustrate and to make a comparison between the two methods, numerical simulations are carried out using a thirteenth-order controlled plant. It is to be noted that the GHR method can yield quasi-optimal controllers in the sense of minimizing quadratic performance indices. The designed controllers, however, do not have enough stability margin, and the order reduction resulting from full state controllers may not be satisfactory. On the other hand, reduced-order controllers in the NFA method can be designed with increased stability margin at the expense of the performance index. For all simulation cases, the NFA method yields second-order controllers with a better stability margin than those by the GHR method. Thus, the NFA method provides an effective method for synthesizing robust reduced-order controllers. **Author** 

## AERONAUTICAL ENGINEERING

A Continuing Bibliography (Suppl. 230)

SEPTEMBER 1988

#### 01

#### **AERONAUTICS (GENERAL)**

## A88-37176 INTERNATIONAL POWERED LIFT CONFERENCE AND EXPOSITION, SANTA CLARA, CA, DEC. 7-10, 1987, PROCEEDINGS

Conference and Exposition sponsored by SAE, DOT, DOD, and NASA. Warrendale, PA, Society of Automotive Engineers, Inc. (SAE P-203), 1988, 815 p. For individual items see A88-37177 to A88-37238. (SAE P-203)

The present conference on VTOL, STOVL and V/STOL fixed-wing aircraft powered lift discusses hot gas recirculation in V/STOL, flight testing of a single-engine powered lift aircraft, RAF experience with VTOL, near-term improvements of the AV-8B Harrier II. recent advancements in thrust augmentation, lift ejectors for STOVL combat aircraft, the correlation of entrainment and lift enhancement for a two-dimensional propulsive wing, the thrust efficiency of powered lift systems, and flight propulsion control integration for V/STOL aircraft. Also discussed are VSTOL design implications for tactical transports, the numerical investigation of a jet in ground effect with a cross flow, the NASA supersonic STOVL propulsion technology program, the aeroacoustics of advanced STOVL aircraft plumes, powered lift transport aircraft certification criteria status, the application of vectored thrust V/STOL experience in supersonic designs, wave drag and high speed performance of supersonic STOVL fighter configurations. and the impact of bypass ratio on thrust-to-weight for V/STOL.

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## A88-37205 ADVANCED TACTICAL TRANSPORT NEEDS AND DESIGN IMPLICATIONS

ROY C. LECROY and THOMAS B. BARNES (Lockheed-Georgia Co., Marietta) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 371-379, refs

(SAE PAPER 872337)

A comprehensive data base has been developed for the critical mission requirements of a next-generation technology Advanced Tactical Transport, and six alternative baseline design concepts (ASTOL, STOL, and VSTOL, with and without low-observability technology) are considered in view of relative mission effectiveness, cost, supportability, survivability, technology, and system programmatics. The data base used is sufficiently wide-ranging and detailed to support the inclusion of affordability and operational policy considerations in the requirements-definition phase of a development program.

O.C.

## A88-37206 VSTOL DESIGN IMPLICATIONS FOR TACTICAL TRANSPORTS

JAMES W. WOLLASTON and DERRELL L. BROWN (Douglas

Aircraft Co., Long Beach, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 381-392. (SAE PAPER 872338)

The advanced Transport Technology Mission Analysis (ATTMA) study, a broad-based investigation of future tactical airlift system concepts, identified the need for an Advanced Tactical Transport (ATT) to support friendly forces on the extended airland battlefield, including deep operations. This paper, which is based on the study, discusses the three major issues for tactical airlift in this environment: the size of the ATT required to support deep operations, the survivability of a penetrating airlifter and its related design requirements, and the suitability of STOL and VSTOL designs for delivery near the desired destination, with limited ground exposure. Finally, the design implications of VSTOL are addressed, and a VSTOL ATT is shown to be cost-competitive with the C-130. However, a STOL ATT has the lowest cost of all alternatives examined.

**A88-37238\*** Royal Aircraft Establishment, Farnborough (England).

#### OVERVIEW OF THE US/UK ASTOVL PROGRAM

FRANK W. ARMSTRONG (Royal Aircraft Establishment, Farnborough, England) and JACK LEVINE (NASA, Washington, DC) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 797-805. (SAE PAPER 872365)

An account is given of progress to date in a US/UK advanced, supersonic flight-capable, powered-lift aircraft development collaborative effort formalized in January, 1986 by a memorandum of understanding (MOU). MOU-related work has investigated such ASTOVL propulsion configuration concepts as the remote augmented lift system, using a two-mode powerplant; augmenting ejectors, which generate a more benign ground environment; plenum chamber burning vectored thrust, which elaborates the geometry of the Harrier Pegasus powerplant; and tandem fans, which are also closely related to the Harrier concept but incorporate a truly variable-cycle engine.

#### A88-37297#

### NEW STRUCTURAL TECHNOLOGIES FOR THE DORNIER 328 FUSELAGE

EBERHARD JOHST and REINER TESKE Dornier-Post (English Edition) (ISSN 0012-5563), no. 1, 1988, p. 55-58.

The Do 328 regional airliner will employ a variety of novel materials and structures techniques in its 30-passenger pressurized fuselage in order to achieve the requisite lightness, cost-efficiency, and acoustical optimization. Attention is presently given to the results obtained to date with test articles in which the Al-Li material and structural design techniques to be used in the Do 328 have been subjected to severe fatigue and acoustical tests, with a view to pressurized fuselage damage tolerance and cabin noise attenuation.

O.C.

#### A88-38710#

#### SKUNK WORKS PROTOTYPING

HAROLD C. FARLEY and RICHARD ABRAMS (Lockheed Aeronautical Systems Co., Burbank, CA) IN: AIAA Flight Test

Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 72-84.

(AIAA PAPER 88-2094)

This paper discusses the Skunk Works' management approach to prototype development programs. A historical perspective of different types of prototype programs is presented along with descriptions of some of the more notable Skunk Works' prototypes. The paper then highlights the Company's preferred system of management along with important factors to be considered in the planning and conduct of a prototype program.

A88-38723#

#### AIR FORCE ONE REPLACEMENT PROGRAM - AN APPLICATION OF ACQUISITION STREAMLINING AND FEDERAL AVIATION ADMINISTRATION CERTIFICATION

ROBERY I. MARX, RAYMOND E. JOHNS (USAF, Wright-Patterson AFB, OH), and JOHN T. HIGGS (Boeing Military Airplane Co., Seattle, WA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 184-205. refs (AIAA PAPER 88-2123)

Acquisitions-streamlining imperatives recently instituted at the U.S. DOD have led to a growing reliance on the FAA certification of military-derivative aircraft. Attention is presently given to the Air Force One Replacement Program, also known as the VC-25A, in which commercial acquisition and testing practices will be applied to two Boeing 747-200 aircraft. The impact of concurrent development, test, and production on the more accustomed methods of DOD acquisition are discussed, and further recommendations for acquisition streamlining are formulated.

A88-38752#

#### TESTING NEW AIRCRAFT - IS THERE AN R&M CHALLENGE? PETER BITTER IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 453-462. (AIAA PAPER 88-2182)

Due to the growing complexity of new aircraft, the fulfillment of reliability and maintainability (R&M) requirements during flight testing is becoming more difficult to achieve. Attention is presently given to the role of supportability criteria in flight tests, R&M data-collection methods, proof-of-compliance testing techniques, and the consolidation of design assumptions for environmental stress.

A88-38753#

#### MAINTAINABILITY - A DESIGN PARAMETER

JAMES E. HOFF (BDM Corp., Albuquerque, NM) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 463-468.

(AIAA PAPER 88-2184)

This paper discusses maintainability as a design parameter. The discussion is slanted to provide the design engineer with the user prespective of maintainability. It presents the various maintainability factors that are evaluated by the users operational Author test and evaluation agency.

A88-38754#

#### RELIABILITY AND MAINTAINABILITY EVALUATION DURING **FLIGHT TEST**

JAN M. HOWELL (USAF, Edwards AFB, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 469-473.

(AIAA PAPER 88-2185)

Extensive reliability and maintainability (R&M) evaluations, quantitative and qualitative, are accomplished during initial testing to ensure that the highest quality weapons system is delivered to the user within cost and schedule constraints. Because of the ever increasing cost-of-ownership of modern weapons system, the emphasis on these evaluations is increasing proportionately. This paper presents an overview of these evaluations. The objectives, methodology used and information available from such evaluations are discussed. The statistical analysis and methods normally associated with the R&M engineering discipline is deemphasized.

A88-39325

#### OSPREY'S VSLED - REWRITING THE MAINTENANCE MANUAL

Rotor and Wing International (ISSN EDWARD W. BASSETT 0191-6408), vol. 22, June 1988, p. 32, 49.

The V-22 Osprey tilt-rotor VTOL aircraft's vibration, structural life, and engine diagnostics (VSLED) system, which is intended to increase in-flight safety and reduce the number of maintenance hours by 50 percent by comparison with helicopters of equivalent class, consists of a 16-bit/word airborne computer unit and a sensor network. The VSLED will analyze data and generate a status report advising V-22 maintenance crews as to the need to repair, overhaul, or replace airframe or engine components. The sensors furnish data on rotor vibration, wing root and empennage strain, and engine vibration. VSLED calculates four life-usage indices through its engine-monitoring features.

A88-39416#

#### CFRP LANDING FLAPS FOR THE AIRBUS A320

WOLFGANG STAEUDLIN and ERNST KLANN **Dornier-Post** (English Edition) (ISSN 0012-5563), no. 2, 1988, p. 31-33.

The A320 airliner's wing landing flap consists of a CFRP torque box with metallic attachment and drive fittings, a CFRP sandwich shell leading edge structure, and a two-part metallic, lightningprotection trailing edge. The torque-box's stringer-reinforced shells are produced as integral parts in one curing process. Flap sectional and bearing loads, together with the very complex bearing and drive structures, were calculated by FEM; CADAM was used throughout, as were NC procedures for fittings. Tests have established that a 4-lb birdstrike at 84 m/sec O.C. would not result in flap loss.

A88-40386

#### IR GROUP ACTIVITIES AT THE ISRAEL AIRCRAFT **INDUSTRIES**

S. JACOBSON, S. WEISROSE, M. LINDNER, Z. LISSAK, Y. YOAV (Israel Aircraft Industries, Ltd., Lod, Israel) et al. IN: Infrared technology XIII; Proceedings of the Meeting, San Diego, CA, Aug. 18-20, 1987. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1987, p. 139-149.

Fields of active IR technology development at Israel Aircraft Industries are evaluated with a view to expansion of the state-of-the-art in IR signature prediction and measurement through a program of ground static and dynamic flight studies. Attention is given to software capabilities for the calculation of different targets' IR signatures. The accuracy of some of these codes has been demonstrated by comparison with experimental data. O.C.

A88-40522

#### **AEROSPACE EQUIPMENT - EVOLUTION AND FUTURE** PROBLEMS [LES EQUIPEMENTS AEROSPATIAUX -**EVOLUTION ET PROBLEMES D'AVENIR]**

MICHEL HUCHER Navigation (Paris) (ISSN 0028-1530), vol. 36, April 1988, p. 253-267. In French.

The status of the French aircraft equipment industry is reviewed, and the navigation segment is analyzed, with emphasis on civil aviation applications. Data show the relative importance of the French industry in helicopter and business aircraft manufacturing with respect to the world market. Radionavigation equipment is considered, and the technology involved in the Navstar/GPS system is described. Inertial guidance systems for autonomous aircraft navigation are also discussed, with particular attention given to the A320 Air Data and Inertial Reference System.

A88-40532#

OPTICAL TECHNOLOGY APPLICATION IN AIRCRAFT

KIYOMICHI MITSUHASHI, RYOZO SEO, and MASAHIKO YOKOTA Japan Society for Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 36, no. 408, 1988, p. 18-25. In Japanese.

**A88-40552\*** National Aeronautics and Space Administration, Washington, D.C.

#### **ROTORCRAFT RESEARCH AT NASA**

JOHN S. BURKS (NASA, Washington, DC) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 12-17.

An overview of NASA research in rotorcraft technology is presented. Ten percent of the NASA aeronautics program is made up of rotorcraft research. The aeronautics program conducts research in five areas: aerodynamics, propulsion, materials and structures, information sciences and human factors, and flight systems. The key objectives of NASA research are major reduction in external noise and aircraft vibration, reduction of pilot workload for night, adverse weather and NOE flying, increasing power and reducing fuel consumption in small engines, and identifying and exploiting vehicle characteristics and concepts for triple current speed and improved maneuverability and agility. NASA and Army resources are combined to pursue research at three major centers. The Ames research center conducts research in the physics of transition and turbulent flows, using a new improved wind tunnel and the NAS system. At the Langley Research Center, work is done in noise and vibration reduction, finding lighter and more durable composite structures, and aeroelasticity for tilt motors and X-wing configurations. At the NASA Lewis Research Center, researchers are working on improving helicopter propulsion systems.

**A88-40553\*** National Aeronautics and Space Administration, Washington, D.C.

### THE NASA/AHS ROTORCRAFT NOISE REDUCTION PROGRAM

OTIS S. CHILDRESS, JR. (NASA, Washington, DC) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 18-22.

Research of the NASA/AHS noise reduction program is discussed, stressing work in four areas: noise prediction, testing and data base, noise reduction, and criteria development. A program called ROTONET has been developed, using a code structure divided into four main parts; main- and tail-rotor blade geometry, rotor performance, noise calculations, and noise propagation. Wind tunnel tests on individual rotors, and flight tests on a helicopter built specifically to generate a broadband main rotor noise data base have been conducted. In the field of noise reduction, researchers have performed analytical evaluations of low noise rotor concepts, and small-scale wind tunnel evaluations of noise reduction concepts. Under the supervision of the FAA, the program in conducting tests to develop criteria for helicopters and heliports.

#### A88-40555

#### RISING TO THE CHALLENGE - RESEARCH AT AATD

JOHN E. KEMPSTER (U.S. Army, Aviation Applied Technology Directorate, Fort Eustis, VA) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 32-36.

Six helicopter related R&D programs of the U.S. Army's Aviation Applied Technology Directorate (AATD) are discussed. The Advanced Composite Airframe Program (ACAP) studies advanced composite materials and design concepts to reduce acquisition cost and airframe structural weight and to improve production and structural performance. ACAP is also investigating the use of composite airframe structures to improve crashworthiness, lightning strike protection and internal acoustic noise levels. The Advanced Digital/Optical Control System (ADOCS) uses digital control law processing and fiber-optic data transmission to improve helicopter combat capability. The Turbine Advanced Gas Generator-Medium/Engine 21 (TAGG-M/Engine 21) program studies engine design to provide advanced propulsion technology for military helicopters. The Advanced Technology Demonstrator Engine (ATDE) program evaluates levels of engine technology for transition into a low-risk engineering development program. The

Multi-Sensor Fusion Demonstration Program (MSFD) is researching the amount and type of information that can be displayed to the complex combat vehicle/aircraft operator. The Enhanced Diagnostic System program is used to implement extensive diagnostic capabilities at the component level and provide expert system test equipment.

#### A88-40556

### THE ROTORCRAFT CENTER OF EXCELLENCE AT THE UNIVERSITY OF MARYLAND

J. GORDON LEISHMAN and ALFRED GESSOW (Maryland, University, College Park) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 46-50.

Study at the Center for Rotorcraft Education and Research (CRER) at the University of Maryland is discussed. Research at CRER focuses on rotating wing technology, including dynamics, aerodynamics, aeroelasticity, structures and composite materials, flight mechanics and the interactions of these disciplines. Specific topics of research include aeroelastic stability, the dynamics of composite rotor blades, the application of higher harmonic control (HHC) to reduce inherent vibration, the effects of interactions between the rotor and the fuselage, flight mechanics, and composite structures. Rotorcraft research facilities at CRER include a rotor test rig for testing hub and blade configurations in hover and forward flight, a structural dynamics test facility and a composite materials laboratory.

#### A88-40557

## RESEARCH AT RENSSELAER POLYTECHNIC INSTITUTE'S CENTER OF EXCELLENCE IN ROTORCRAFT TECHNOLOGY

ROBERT G. LOEWY (Rensselaer Polytechnic Institute, Troy, NY) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 53-59. refs

A discussion of research at the Rensselaer Polytechnic Institute's Rotorcraft Technology Center (RPI-RTC) is given, stressing study in four areas: materials and structures for rotorcraft. structural dynamics of components unique to rotorcraft, unsteady aerodynamics of rotors, and aeroelasticity of rotors and rotor/fixed airframe combinations. Research in materials and structures emphasizes composite structures to prevent warping and fatigue. The center is researching rotorcraft drive shaft system design and fuselage structural dynamics. In the field of rotor unsteady aerodynamics, the center studies compressibility by generating a two-dimensional vortex and observing its interaction with a two-dimensional lifting. Two studies in rotor aeroelasticity are being conducted, one to establish methodology which could account for the nonlinearities associated with large deflections and moderate rotations, and another examining the effect of rotor blade nonlinear dynamics on forced response.

#### A88-40558

### 1987 TECHNICAL COMMITTEE HIGHLIGHTS - THE YEAR IN REVIEW

RAJARAMA K. SHENOY, KENNETH R. READER, EVAN A. FRADENBURGH, CARL J. BENNING, GENE SADLER et al. Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 60-70, 72-79.

Reports from the AHS Technical Committees for 1987 are given, discussing advances in various fields of helicopter research, including dynamics, propulsion, manufacturing and product assurance, military operations, and product support. In the field of acoustics, external and internal noise research continued, and new developments were made in noise prediction methodology. In aerodynamic studies, progress was made in the areas of CFD and experimental data base development, with studies on rotor wakes and airflow, and BVI. In the field of aircraft design, two new helicopters, the Boeing 360 Tandem Rotor and the Westland-Agusta EH 101, were introduced and tilt rotor research continued. LHX activities dominated the field of avionics and systems. In structures and materials research, work was done in composite structures design, fabrication, and testing. Test and evaluation activities have focused on modifications to or variants

of existing military and commercial aircraft, research into emerging technology, and technology demonstrations for future VTOL applications.

#### A88-40559

### AIRCRAFT WITHOUT AIRPORTS - CHANGING THE WAY MEN

HANS MARK (Texas, University, Austin) and ROBERT R. LYNN (Bell Helicopter Textron, Fort Worth, TX) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 80-83, 86, 87.

Tilt rotor vehicles are discussed, giving the history, present state, and prospects for future development of rotor tilt technology. An overview of tilt rotor aircraft designs from 1938 up to the present is given, culminating with the introduction of the V-22 Osprey, currently being developed for the Marine assault mission. The Osprey will have over 300 knot speed capability and an altitude of up to 30,000 ft, combined with helicopter-type hover ability. The Osprey will be largely constructed from high strength graphite. A commercial version of the Osprey is expected by 1995. New developments in tilt rotor designs will provide increased speed, lower weight and increased payload, making the use of tilt rotor craft for commercial passenger flying more feasible.

#### A88-40560

#### RESEARCH AND DEVELOPMENT AT BOEING HELICOPTERS BRUCE B. BLAKE (Boeing Helicopters, Philadelphia, PA) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 90-95.

The Boeing Helicopters R&D program, involving the Army's CH-47D/MH-47E Chinook medium lift helicopter, the V-22 Osprey multi-service TiltRotor aircraft, and the Army's LHX armed reconnaissance aircraft is discussed, stressing developments in aeromechanics and vehicle design, new materials applications, and flight controls and avionics. The Osprey program was the first rotorcraft program to make significant use of CFD methods. CFD codes have also been applied to rotor acoustic analysis and prediction. Composites have been used to reduce craft weights and improve aerodynamic efficiency, safety, and survivability. Research is being conducted to improve inspection methods and to reduce the cost of composites. Digital electronics systems have reduced cost per function and increased craft capability as a weapon system. The Advanced Digital/Optical Control System (ADOCS) is being used. Other research has focused on the Boeing Model 360 Advanced Technology Demonstrator aircraft, which has an integrated flight management system, incorporating digital avionics and cathode ray tube displays.

#### A88-40561 ROTORCRAFT TECHNOLOGY DEVELOPMENT AT SIKORSKY

PETER ARCIDIACONO (United Technologies Corp., Sikorsky Vertiflite (ISSN 0042-4455), vol. 34, Aircraft Div., Stratford, CT) May-June 1988, p. 96-101.

Work done at Sikorsky Aircraft in advanced rotors, advanced airframes, vibration and noise, vehicle flight management, cost of ownership and advanced and alternative rotorcraft is discussed in detail. Studies of rotors include making optimum use of composites, metals and elastomerics, developing bearingless main rotors utilizing flexbeams, and improving airfoil and rotor performance. Airframe research is making use of metals and composites, especially aluminum-lithium, to decrease craft weight. CFD and computational structural dynamics are being used to reduce vibration and internal noise. In the field of vehicle flight management, analyses, software techniques, and simulation hardware are being developed to study and integrate the elements of man-machine interface. Ways of reducing cost are sought through designing new hardware with MANPRINT requirements in mind and employing emerging new technology involved with structural and mechanical systems monitoring. Studies in alternative rotorcraft configurations have focused on the X-wing vehicle.

#### A88-40562

## CURRENT ROTORCRAFT TECHNOLOGY ADVANCEMENT AT

HELMUT B. HUBER (Messerschmitt-Boelkow-Blohm GmbH, Munich, Federal Republic of Germany) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 106-112.

A review of rotorcraft R&D at MBB is given. In the area of aerodynamics, research focuses on developing and testing advanced rotor blade airfoils. Research on new rotor systems includes the development of a 5-blade hingeless rotor system and work on bearingless main rotors and tail rotors. Anti-vibration research stresses the study of vibration control by rotor isolation and active control techniques. Studies of composite airframe structures are being conducted, using the BK 117 as a technology demonstrator and avionics systems are tested both in flight and with the CGI-Simulator. Technology used in research includes CFD-codes, mathematical helicopter models, and two new simulators, and special configurations are being developed for a European tilt rotor aircraft and a single-pilot fighter aircraft compounded with a ducted fan propulsor.

#### N88-22003# Transportation Systems Center, Cambridge, Mass. GENERAL AVIATION ACTIVITY AND AVIONICS SURVEY: 1986 DATA Annual Summary Report

Dec. 1987 290 p

(AD-A189986; DOT-TSC-FAA-87-5; FAA-MS-87-5) Avail: NTIS HC A13/MF A01 CSCL 01C

This report presents the results and description of the 1986 General Aviation Activity and Avionics Survey. The survey was conducted during 1987 by the FAA to obtain information on the activity and avionics of the United States registered general aviation aircraft fleet, the dominant component of civil aviation in the U.S. The survey was based on a statistically selected sample of about 10.5 percent of the general aviation fleet. A response rate of 54.6 percent was obtained. Survey results are based upon responses but are expanded upward to represent the total population. Survey results revealed that during 1986 an estimated 34.4 million hours of flying time were logged and 95.1 million operations were performed by the 220,044 active general aviation aircraft in the U.S. fleet. The mean annual flight time per aircraft was 148.9 hours. The active aircraft represented about 81.9 percent of the registered general aviation fleet. The report contains breakdowns of these and other statistics by manufacturer/model group, aircraft type, state and region of based aircraft, and primary use. Also included are fuel consumption, lifetime airframe hours, avionics, engine hours, and miles flown estimates, tables for detailed analysis of the avionics capabilities of the general aviation fleet, estimates of the number of landings, IFR hours flown, and the cost and grade of fuel consumed by a GA fleet.

#### Deutsche Lufthansa Aktiengesellschaft, Cologne N88-22855 (West Germany).

#### **ACTIVITIES REPORT OF LUFTHANSA Annual Report, 1987** [LUFTHANSA JAHRBUCH '87]

HANS-JOACHIM ALLGAIER, ed. 31 May 1987 309 p In **GERMAN** 

(ISSN-0176-5086; ETN-88-91474) Avail:

Fachinformationszentrum Karlsruhe, 7514

Eggenstein-Leopoldshafen 2, Fed. Republic of Germany

The economic significance of Lufthansa; Lufthansa in the capital market; flight as a financial problem; pilot education; responsibility of the aircraft captain; aircraft safety; use of twin-engine long distance aircraft; customer information; operation of the Frankfurt air freight center; and Airbus Industries are discussed. The evolution of European air traffic policy; extraterrestrial application of air law, and the status of aircraft engineering are reviewed. ESA

### N88-22856# Fokker B.V., Amsterdam (Netherlands). ACTIVITIES REPORT IN AEROSPACE Annual Report, 1986 [JAARVERSLAG 1986]

1986 60 p In DUTCH Original contains color illustrations (ETN-88-91566) Avail: NTIS HC A04/MF A01

The development, production, and commercial activities related

to the F-27 Friendship, Fokker 50, Fokker 100, Airbus 300, Airbus 310, Short 330, Short 360, and F-16 are summarized. Planned research activities in astronautics are mentioned.

#### 02

#### **AERODYNAMICS**

Includes aerodynamics of bodies, combinations, wings, rotors, and control surfaces; and internal flow in ducts and turbomachinery

#### THE USE OF OPTIMIZATION TECHNIQUE AND THROUGH FLOW ANALYSIS FOR THE DESIGN OF AXIAL FLOW COMPRESSOR STAGES

ARISTIDE MASSARDO and ANTONIO SATTA (Genova, Universita, Genoa. Italy) IN: Conference on Fluid Machinery, 8th, Budapest, Hungary, Sept. 1987, Proceedings. Volume 1. Budapest, Akademiai Kiado, 1987, p. 455-463. refs

In the present automated procedure, which has been developed for the aerodynamic design optimization of axial flow compressor stages' geometry, a numerical optimization technique is coupled with a code that conducts a through-flow analysis. Losses are evaluated on the basis of correlations derived from the available literature, and results characterized by good stability, high precision. and short calculation times are established. Attention is given to illustrative examples.

#### A88-37177

#### **HOVER SUCKDOWN AND FOUNTAIN EFFECTS**

RICHARD E. KUHN IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 1-17. refs (SAE PAPER 872305)

The flow fields encounterd by jet- and fan-powered vertical/short takeoff and landing (V/STOL) aircraft when hovering in ground effect are reviewed, and their effects on the aerodynamic characteristics are discussed. The ground effects considered include the suckdown generated by the flow from a single nozzle, the fountain effects generated by multiple-nozzle configurations. and the additional suckdown associated with the fountain flow generated by multiple-nozzle configurations. Current understanding of the flow fields involved, and the capability and limitations of available methods for estimating the effects of ground proximity, are reviewed and the areas where additional work is needed are discussed.

#### A88-37178

#### HOT GAS RECIRCULATION IN V/STOL

C. M. MILFORD (British Aerospace, PLC, Military Aircraft Div., Kingston-upon-Thames, England) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 19-29. refs (SAE PAPER 872306)

An account is given of hot gas recirculation (HGR) mechanisms in V/STOL aircraft, as well as of ways in which to assess and control it, since severe HGR can result in large thrust losses and compressor stall. Since full scale data on HGR is limited, it is necessary to rely heavily on model testing. Attention is accordingly given to scaling principles; it is shown that it is not possible to achieve similarity in all test parameters simultaneously. CFD is noted to show promise, but a full, time-dependent HGR computation remains beyond the capability of generally available computers.

National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

#### PROPULSION-INDUCED EFFECTS CAUSED BY **OUT-OF-GROUND EFFECTS**

RICHARD MARGASON (NASA, Ames Research Center, Moffett IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 31-57. Previously announced in STAR as N88-14088. refs (SAE PAPER 872307)

Propulsion induced effects encountered by moderate- to high-disk loading STOVL or VSTOL aircraft out-of-ground effect during hover and transition between hover and wing-borne flight are discussed. Descriptions of the fluid flow phenomena are presented along with an indication of the trends obtained from experimental investigations. In particular, three problem areas are reviewed: (1) the performance losses sustained by a VSTOL aircraft hovering out-of-ground effect, (2) the induced aerodynamic effects encountered as a VSTOL aircraft flies on the combination of powered and aerodynamic lifts between hover and cruise out-of-ground effect, and (3) the aerodynamic characteristics caused by deflected thrust during maneuvering flight over a wide range of both angle of attack and Mach number.

#### **A88-37180**

#### EFFECT OF GROUND PROXIMITY ON THE AERODYNAMIC CHARACTERISTICS OF THE STOL AIRCRAFT

VEARL R. STEWART IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. (SAE PAPER 872308)

The aerodynamics of the STOL aircraft can experience significant changes in proximity to the ground. A review of the existing data base and methodologies has been made and the results of that review are presented in this paper. The existing data show that in ground proximity the STOL aircraft will generally experience a reduction in the lift component regardless of the lifting configuration. Those configurations with integrated power and lift systems will have an additional effect of ground induced aerodynamic changes. This paper will discuss the existing data base and the deficiencies of that data base.

#### THE GROUND ENVIRONMENT CREATED BY HIGH SPECIFIC THRUST VERTICAL LAND AIRCRAFT

P. G. KNOTT (British Aerospace, PLC, London, England) International Powered Lift Conference and Exposition, Santa Clara. CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 75-85. refs (SAE PAPER 872309)

When high specific thrust engines vectored for vertical landing are in ground proximity, the high-pressure, high-temperature exhaust plumes create a hostile environment for the aircraft, ground crew, equipment, and landing platform. An account is presently given of the physical nature of the ground surface erosion. near-field/midfield noise, upwash impingement on aircraft, and ground sheet temperature problems that arise in these conditions, with a view to the formulation of suggestions toward their amelioration.

#### ARR-37194

#### CORRELATION OF ENTRAINMENT AND LIFT ENHANCEMENT FOR A TWO-DIMENSIONAL PROPULSIVE WING

D. R. WILSON, C. S. JEON, B. R. WINBORN (Texas, University, Arlington), and C. PERNICE IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers. Inc., 1988, p. 235-242. refs (SAE PAPER 872325)

Wind tunnel model flow entrainment and lift enhancement results for a modified NACA 0025 airfoil section with propulsive nozzle exhausting over the upper surface of the airfoil at the

70-percent chord position are presented and correlated for alpha values of -5, 0, 5, 10, and 15 deg; wind tunnel dynamic pressures were 0, 1, 5, and 10 lbf/sq ft. The lift coefficient and entrainment velocity increment were found to directly correlate with the propulsive velocity increment. Linear correlations based on momentum pressure parameters using a 'neutral point' concept were also found to provide an excellent correlation of lift O.C. enhancement and entrainment velocity.

A88-37195

EXPERIMENTAL INVESTIGATION OF A JET IMPINGING ON A GROUND PLANE IN THE PRESENCE OF A CROSS FLOW

J. M. CIMBALA, D. R. STINEBRING, A. L. TREASTER, M. L. BILLET (Pennsylvania State University, University Park), and M. M. WALTERS (U.S. Navy, Naval Air Development Center, Warminster, PA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 243-251. Navy-supported research. refs (SAE PAPER 872326)

An experimental investigation has been conducted in a wind tunnel to model the impingement of high velocity jet exhaust flow on the ground, as encountered by vertical or short takeoff and landing (VSTOL) aircraft. A constant jet velocity was maintained while varying the wind tunnel cross flow velocity, upstream boundary layer thickness, and height from the ground to the jet exit plane. The radial wall jet, when interacting with the cross flow, forms an oscillating horseshoe-shaped separation bubble, commonly referred to in the literature as a ground vortex. The streamwise distance of the separation point from the jet impingement point is documented here as a function of the flow parameters and geometry. Flow visualization of the flow field above the ground plane and two-component laser Doppler velocimeter measurements taken through the separation bubble indicate that the separation bubble is highly unsteady and non-symmetric. This unsteadiness may be related to shear layer vortices shed from the lip of the Author

A88-37209\* Florida Univ., Gainesville. NUMERICAL SIMULATION OF A SUBSONIC JET IN A **CROSSFLOW** 

KARLIN R. ROTH (Florida, University, Gainesville) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 425-431. refs (Contract NCC2-403)

(SAE PAPER 872343)

The aerodynamic/propulsive interaction between a subsonic jet exhausting perpendicularly through a flat plate into a crossflow is investigated numerically using an approximately factored, partially flux-split, implicit solver for the three-dimensional, thin-layer Navier-Stokes equations. This algorithm is applied to flows with a range of jet-to-crossflow velocity ratios between 4 and 8. The computations model the jet trajectory, the contrarotating vortex pair and the wake region near the plate downstream of the jet orifice. Both qualitative and quantitative agreement with the existing experimental database are demonstrated. Flow visualization is instructive for understanding the physics of this flowfield.

National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif. NUMERICAL INVESTIGATION OF A JET IN GROUND EFFECT

WITH A CROSSFLOW W. R. VAN DALSEM, A. G. PANARAS, and J. L. STEGER (NASA, Ames Research Center, Moffett Field, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec.

7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 433-445. refs (SAE PAPER 872344)

One of the flows inherent in V/STOL operations, the jet in ground effect with a crossflow, is studied using the Fortified Navier-Stokes (FNS) scheme. Through comparison of the simulation results and the experimental data, and through the variation of the flow parameters (in the simulation) a number of interesting characteristics of the flow have been observed. For example, it appears that the forward penetration of the ground vortex is a strong inverse function of the level of mixing in the ground vortex. An effort has also been made to isolate issues which require additional work in order to improve the numerical simulation of the jet in ground effect flow. The FNS approach simplifies the simulation of a single jet in ground effect, but will be even more effective in applications to more complex topologies.

A88-37211 TURBULENCE AND FLUID/ACOUSTIC INTERACTION IN **IMPINGING JETS** 

ROBERT E. CHILDS and DAVID NIXON (Nielsen Engineering and IN: International Powered Research, Inc., Mountain View, CA) Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 447-458. refs (Contract F49620-85-C-0055)

(SAE PAPER 872345)

Enhanced turbulence in an upwash fountain and fluid/acoustic resonance of an impinging axisymmetric jet are investigated by numerical simulations of the mean flow and the largest scales of the unsteady fluid motion. In the planar upwash, the simulated shear stress and spreading rate are three times greater than in a normal jet and are in good agreement with experimental data. Reynolds-stress transport mechanisms which lead to the enhanced turbulence are discussed, and a qualitative description of the large scale turbulent motions is proposed. A model for the pressure-strain term is determined to be a major source of error in Reynolds-stress transport modeling of the upwash. In an axisymmetric impinging jet at a jet Mach number of 0.9, resonant-like behavior with elevated levels of pressure fluctuations and dominance of a single frequency of vortex generation are observed. Vortex stretching is observed to be critical to the generation of noise in the impingement zone.

A88-37212

NUMERICAL SIMULATION OF COMPRESSIBLE FLOW FIELD ABOUT COMPLETE ASKA AIRCRAFT CONFIGURATION

SUSUMU TAKANASHI (National Aerospace Laboratory, Chofu, Japan) and KEISUKE SAWADA (Kawasaki Heavy Industries, Ltd., Aircraft Engineering Div., Kobe, Japan) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 459-466. refs (SAE PAPER 872346)

Numerical simulations of compressible inviscid flows are carried out for the complete configuration of experimental aircraft 'ASKA' which adopts the USB technology to increase the amount of lift force. Three different grid systems corresponding to different configurations are generated by a newly developed interactive grid generation method. Euler equations are solved by the second order upwind biased finite volume method. A planar Gauss-Seidel relaxation method is adopted to realize a rapid convergence to steady solutions. Computations are made to see the influences of different arrangements of engine nacelles over the interfered flow fields.

A88-37220\* McDonnell-Douglas Research Labs., St. Louis, Mo. UNSTEADY FEATURES OF JETS IN LIFT AND CRUISE MODES FOR VTOL AIRCRAFT

KIBENS, K. R. SARIPALLI, R. W. WLEZIEN, and J. T. KEGELMAN (McDonnell Douglas Research Laboratories, Saint Louis, MO) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 543-552. refs

(Contract NAS3-24621) (SAE PAPER 872359)

Experiments were performed to simulate jet plume effects associated with VTOL aircraft in takeoff and cruise modes. A water facility was used to investigate the influence of inclination angle and separation distance on the three-dimensional fountain flowfield generated by two impinging jets operating at a jet Reynolds number of 250,000. Substantial differences in the flow features were observed for different spacings between the jets. Plume effects in cruise mode were simulated by a supersonic unheated jet parallel to a wall. Variation of the distance between the wall and the edge of the plume is shown to have a major controlling effect on the supersonic screech instability.

**A88-37222\*** National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

### SUPERSONIC JET PLUME INTERACTION WITH A FLAT

JOHN M. SEINER, JAMES C. MANNING (NASA, Langley Research Center, Hampton, VA), and BERNARD JANSEN (Kentron International, Inc., Hampton, VA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 563-573. refs (SAE PAPER 872361)

Supersonic jet plume interaction with a flat plate was studied using a model scaled test apparatus designed to simulate plume/aircraft structure interaction for the cruise configuration. The generic configuration consisted of a rectangular supersonic nozzle of aspect ratio 7, and a large flat plate located beneath the nozzle at various nozzle plate distances, the plate was instrumented to measure surface dynamic pressure and mean wall temperature, with provisions for measurements of acceleration and strain on coupon size panels that could be inserted in the plate. Phase-averaged schlieren measurements revealed the presence of high-intensity acoustic emission from the supersonic plume above the plate, directed upstream; this radiation could be associated with the shock noise generation. Narrow band spectra of surface dynamic pressure show spectral peaks with amplitude levels reaching 1 psi, related to the screech tones. Temperature measurements indicated elevated surface temperatures in regions of high turbulence intensity.

A88-37225\* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

#### THE RSRA/X-WING EXPERIMENT - A STATUS REPORT

JAMES W. LANE and MARK SUMICH (NASA, Ames Research Center, Moffett Field, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 597-625. refs (SAE PAPER 872371)

This paper reports on the current status of the NASA/Army Rotor Systems Research Aircraft (RSRA)/X-Wing Experiment program designed to demonstrate the technology readiness of the X-Wing concept for a prototype vehicle. Program accomplishments, test results on all of the necessary major hardware elements, and the results of flight tests are described. Future wind tunnel testing of the full-scale rotor system in the NASA NF SAC facility is presently being planned; these tests must be completed before an objective assessment can be made regarding the viability of the RSRA/X-Wing concept for an operational aircraft.

A88-37235\* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

## WAVE DRAG AND HIGH-SPEED PERFORMANCE OF SUPERSONIC STOVL FIGHTER CONFIGURATIONS

DONALD A. DURSTON (NASA, Ames Research Center, Moffett Field, CA) and RONALD K. STONUM (USAF, Washington, DC) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 735-751. refs (SAE PAPER 872311)

A supersonic STOVL fighter aircraft aerodynamic research program is being conducted at NASA Ames Research Center. The research focuses on technology development for this type of

aircraft and includes generating an extensive aerodynamic database and resolving particular aerodynamic uncertainties for various twinand single-engine aircraft concepts. Highlights of the results from this program are presented. The highlights include propulsion-induced effects on the aircraft drag, prediction capabilities, volume integration for minimizing drag, and wave drag and aerodynamic efficiency comparisons. Results indicate that estimated STOVL fighter performance is roughly comparable to the performance of modern conventional fighters in terms of wave drag and aerodynamic efficiency.

A88-37236\* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

### APPLICATION OF EMPIRICAL AND LINEAR METHODS TO VSTOL POWERED-LIFT AERODYNAMICS

RICHARD MARGASON (NASA, Ames Research Center, Moffett Field, CA) and RICHARD KUHN IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 753-783. Previously announced in STAR as N88-17581. refs (SAE PAPER 872341)

Available prediction methods applied to problems of aero/propulsion interactions for short takeoff and vertical landing (STOVL) aircraft are critically reviewed and an assessment of their strengths and weaknesses provided. The first two problems deal with aerodynamic performance effects during hover: (1) out-of-ground effect, and (2) in-ground effect. The first can be evaluated for some multijet cases; however, the second problem is very difficult to evaluate for multijets. The ground-environment effects due to wall jets and fountain flows directly affect hover performance. In a related problem: (3) hot-gas ingestion affects the engine operation. Both of these problems as well as jet noise affect the ability of people to work near the aircraft and the ability of the aircraft to operate near the ground. Additional problems are: (4) the power-augmented lift due to jet-flap effects (both inand out-of-ground effects), and (5) the direct jet-lift effects during short takeoff and landing (STOL) operations. The final problem: (6) is the aerodynamic/propulsion interactions in transition between hover and wing-borne flight. Areas where modern CFD methods can provide improvements to current computational capabilities are identified.

A88-37353\* National Aeronautics and Space Administration.
Ames Research Center, Moffett Field, Calif.
CALCULATION OF EXTERNAL-INTERNAL FLOW FIELDS FOR

### MIXED-COMPRESSION INLETS

W. J. CHYU, T. KAWAMURA, and D. P. BENCZE (NASA, Ames Research Center, Moffett Field, CA) (University of Texas, NSF, U.S. Navy, et al., World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986) Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 64, Oct. 1987, p. 21-37. Previously announced in STAR as N87-24434. refs

Supersonic inlet flows with mixed external-internal compressions were computed using a combined implicit-explicit (Beam-Warming-Steger/MacCormack) method for solving the three-dimensional unsteady, compressible Navier-Stokes equations in conservation form. Numerical calculations were made of various flows related to such inlet operations as the shock-wave intersections, subsonic spillage around the cowl lip, and inlet started versus unstarted conditions. Some of the computed results were compared with wind tunnel data.

## A88-37355\* Old Dominion Univ., Norfolk, Va. FLOW SOLUTION ON A DUAL-BLOCK GRID AROUND AN AIRPLANE

LARS-ERIK ERIKSSON (Old Dominion University, Norfolk, VA) (University of Texas, NSF, U.S. Navy, et al., World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986) Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 64, Oct. 1987, p. 79-93. refs (Contract NAG1-363)

The compressible flow around a complex fighter-aircraft

configuration (fuselage, cranked delta wing, canard, and inlet) is simulated numerically using a novel grid scheme and a finite-volume Euler solver. The patched dual-block grid is generated by an algebraic procedure based on transfinite interpolation, and the explicit Runge-Kutta time-stepping Euler solver is implemented with a high degree of vectorization on a Cyber 205 processor. Results are presented in extensive graphs and diagrams and characterized in detail. The concentration of grid points near the wing apex in the present scheme is shown to facilitate capture of the vortex generated by the leading edge at high angles of attack and modeling of its interaction with the canard wake.

#### A88-37356 SIMULATION OF TRANSONIC FLOW IN RADIAL COMPRESSORS

LARS-ERIK ERIKSSON (Norges Tekniske Hogskole, Trondheim, Norway) (University of Texas, NSF, U.S. Navy, et al., World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986) Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 64, Oct. 1987, p. 95-111. Research supported by the Norges Teknisk-Naturvitenskapelige Forskningsrad and Norges Tekniske Hogskole. refs

A collection of computer codes for the generation of grids and the solution of the Euler equations have been developed for the purpose of simulating the complex three-dimensional transonic and rotational flow through high pressure ratio radial compressors. The grid generation procedure is based on transfinite interpolation and generates smooth grids of H-, C-, and O-type with a minimum of operations. The Euler solution procedure is based on a centered finite volume scheme with explicit Runge-Kutta time integration and absorbing inflow/outflow boundary conditions. An example solution for a high-speed radial compressor with a total pressure ratio of 1:12 demonstrates that the method is robust and preserves both mass and rothalpy through strong shocks. It also demonstrates that shock-induced separations with reverse flow can be captured by the numerical procedure.

## A88-37358 RECENT DEVELOPMENTS AND ENGINEERING APPLICATIONS OF THE VORTEX CLOUD METHOD

R. I. LEWIS (Newcastle-upon-Tyne, University, England) (University of Texas, NSF, U.S. Navy, et al., World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986) Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 64, Oct. 1987, p. 153-176. refs

Following a brief summary of the vortex cloud (VC) method, a comparison of two models is made for the case of flow past an isosceles triangular wedge. On the basis of reasonable agreement between these methods a hybrid method has been developed, combining potential flow over the upper surface with sharp edge separation and full VC theory over the lower and rear surfaces. Success for the wedge flow confirms the suitability of this method to air-foils for which the upper surface is prone to 'numerical separation' by full VC theory. Application of the hybrid method to NACA 0025 with an airbrake flap results in considerable improvement of predicted surface pressure, lift coefficient, and drag coefficient.

#### A88-37360 A COMPARISON OF NUMERICAL ALGORITHMS FOR UNSTEADY TRANSONIC FLOW

W. A. SOTOMAYER (USAF, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH), L. N. SANKAR (Georgia Institute of Technology, Atlanta), and J. B. MALONE (Lockheed-Georgia Co., Marietta) (University of Texas, NSF, U.S. Navy, et al., World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986) Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 64, Oct. 1987, p. 237-265. Research supported by the Boeing Military Airplane Co. and Lockheed-Georgia Co. refs

(Contract AF-AFOSR-77-3233; AF-AFOSR-79-0023;

F33615-83-C-3215)

The steady and unsteady transonic flow over an F-5 wing model

is investigated by means of numerical simulations, comparing the performance of the potential codes XTRAN3S (Borland et al., 1980) and USIPWING (Sankar et al., 1981) with that of the Euler code of Sankar et al. (1985). The mathematical derivations of the methods are reviewed, and the results are presented in extensive graphs and characterized in detail with reference to published experimental data. On the clean wing, all three methods gave good results except at M = 0.95 and f = 20 Hz, where a spurious aft shock pulse was predicted. Good agreement was also obtained in simulations with deflected trailing-edge control surfaces and simulations of angle-of-attack effects.

#### A88-37653 NUMERICAL SEPARATION MODELS [CHISLENNYE MODELI SRYVA]

O. M. BELOTSERKOVSKII IN: Problems of turbulent flows. Moscow, Izdatel'stvo Nauka, 1987, p. 32-56. In Russian. refs

Some current problems in aerodynamics are studied by direct numerical analysis using full models, without resorting to semiempirical theories. Emphasis is placed on separation (turbulent) flows in the case of 'limiting' regimes at large Reynolds numbers. New numerical models are developed for this class of flows, and numerical methods are proposed for computer implementation. Ordered structures typical of different classes of turbulent flows are shown.

## A88-37657 TURBULENT FRICTION ON A DELTA WING [TURBULENTNOE

TRENIE NA TREUGOL'NOM KRYLE]
A. D. KHON'KIN, A. F. KISELEV, and P. P. VOROTNIKOV IN: Problems of turbulent flows. Moscow, Izdatel'stvo Nauka, 1987, p. 80-87. In Russian. refs

Experimental data are presented on statistical pressure distribution, friction resistance, and limiting flow line directions on the leeside of a delta wing of small aspect ratio at large angles of attack under conditions of flow separation at the leading edge. Based on the measurements and result of flow visualization, the flow separation and reattachement lines are determined, as are regions of sharp changes in the boundary layer characteristics. The physical picture of flow on the leeside of the wing is reconstructed for relatively large angles of attack.

#### A88-37665

## AXISYMMETRIC TURBULENT COMPRESSIBLE JET IN SUBSONIC COFLOW [OSESIMMETRICHNAIA TURBULENTNAIA SZHIMAEMAIA STRUIA V DOZVUKOVOM SPUTNOM POTOKE]

V. E. KOZLOV, A. N. SEKUNDOV, and I. P. SMIRNOVA IN: Problems of turbulent flows. Moscow, Izdatel'stvo Nauka, 1987, p. 171-177. In Russian. refs

Results of an experimental and analytical study of an axisymmetric turbulent compressible air jet in a subsonic comoving stream are reported. Experimental data are obtained on distributions of axial velocity and characteristic thickness along the axis of a submerged supersonic jet for different internal-to-external pressure ratios. An analysis is carried out for a supersonic nonisobaric jet propagating in a subsonic comoving stream.

#### A88-37697

#### SEPARATION OF A SUPERSONIC BOUNDARY LAYER AHEAD OF THE BASE OF A BODY [OTRYV SVERKHZVUKOVOGO POGRANICHNOGO SLOIA PERED DONNYM SREZOM KONTURA TELA]

M. A. KRAVTSOVA and A. I. RUBAN Zhurnal Vychislitel'noi Matematiki i Matematicheskoi Fiziki (ISSN 0044-4669), vol. 28, April 1988, p. 580-590. In Russian. refs

The separation of supersonic flow near a corner point on a body is analyzed in the context of the asymptotic theory of the interaction between a laminar boundary layer and the external nonviscous part of flow. Particular attention is given to the transition stage of flow during which a pressure increase in the base region leads to the detachment of the separation point from the corner

point and to the displacement of the separation point toward the leading edge of the body. Results of a numerical solution are presented.

#### A88-37919\*# Old Dominion Univ., Norfolk, Va. AN EXPERIMENTAL INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF SLANTED BASE OGIVE CYLINDERS **USING MAGNETIC SUSPENSION TECHNOLOGY**

C. P. BRITCHER (Old Dominion University, Norfolk, VA) and C. IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 117-127, refs

(Contract NAG1-716) (AIAA PAPER 88-2011)

This paper reports on an experimental investigation of aerodynamic characteristics of slanted base ogive cylinders at zero incidence. The Mach number range is 0.05 to 0.3. In this investigation, magnetically suspending the wind tunnel models eliminates flow disturbances associated with mechanical supports. This paper reports on the drastic changes in lift, pitching moment, and drag for a slight change in base slant angle. Flow visualization with liquid crystals and oil is used to observe base flow patterns responsible for the sudden changes in aerodynamic characteristics. This paper also reports on hysteretic effects that are present and discusses computational results using VSAERO and SANDRAG.

A88-37931#

#### CALCULATED VISCOUS EFFECTS ON AIRFOILS AT TRANSONIC SPEEDS

D. W. SINCLAIR (Calspan Corp., Arnold AFB, TN) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 242-247. refs (AIAA PAPER 88-2027)

With available computational techniques, the effect of model scale and boundary-layer transition location on pressure distribution and boundary layer properties is demonstrated. The computational techniques are described, in addition to the methods used to estimate transition location and to model the transition zone. Results for two different wing configurations are presented to illustrate the influence of the presence of the boundary layer on the aerodynamic coefficients and shock location at transonic speeds.

A88-37932\*# National Aeronautics and Space Administration.

#### Langley Research Center, Hampton, Va. VELOCITY PROFILE SIMILARITY FOR VISCOUS FLOW DEVELOPMENT ALONG A LONGITUDINALLY SLOTTED WIND-TUNNEL WALL

JOEL L. EVERHART and SURESH H. GORADIA (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 257-268. refs (AIAA PAPER 88-2029)

A discussion of the flow field measurements on the slot centerline of two different longitudinally slotted wind-tunnel walls is presented. The longitudinal and transverse components of these data are then transformed using the concept of flow similarity to demonstrate the applicability of the technique to the development of the viscous shear flow along and through a slotted wall. Results are presented showing the performance of the similarity transformations with variations in tunnel station, Mach number, and airfoil-induced curvature of the tunnel free stream. Author

#### A88-37933#

#### AERODYNAMIC LAG OF A CLOSE-COUPLED CANARD AIRCRAFT MODEL AT MACH 0.3 TO 1.6

T. D. BUCHANAN and R. W. CAYSE (Calspan Corp., Arnold AFB, IN: Aerodynamic Testing Conference, 15th, San Diego, CA,

May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 269-281. refs (AIAA PAPER 88-2030)

The unsteady loads generated by canard motions on a close-coupled canard aircraft were studied by wind tunnel tests on a scale model of the X-29; these unsteady aerodynamics effects were characterized by the difference in time between the canard motion and the response of the aircraft, or 'lag time'. The tests were performed at Mach 0.3, 0.6, 0.9, and 1.6, at a nominal Reynolds number of 2.0 million/foot and at alpha ranging over a 2-10 deg range at zero and 6-deg yaw angles. Lag times at various frequency ranges were deduced from frequency analyses of the measurement probe outputs; they were 2 msec for canard frequencies in the 30-50 Hz range, and 20 msec for frequencies below 10 Hz.

#### A88-37937\*# Douglas Aircraft Co., Inc., Long Beach, Calif. AN EXPERIMENTAL INVESTIGATION OF FLOWFIELD ABOUT A MULTIELEMENT AIRFOIL

A. NAKAYAMA (Douglas Aircraft Co., Aerodynamics Research and Technology Group, Long Beach, CA), H.-P. KREPLIN (Aerodynamische Versuchsanstalt, Goettingen, Federal Republic of Germany), and H. L. MORGAN (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 311-320. refs

(AIAA PAPER 88-2035)

Detailed measurements of mean-flow and turbulence quantities around a multielement airfoil model have been made using pressure and hot-wire probes. The results obtained in two test cases at the chord Reynolds number of 3 million and the freestream Mach number of 0.2 show a number of features of the complex flows that are important in accurate modeling of these flows by numerical methods. Many parts of the shear flow vastly deviate from classical flows, and the interaction with the external potential flow is very strong.

#### A88-38167

#### ON THE PROSPECTS FOR INCREASING DYNAMIC LIFT

D. G. MABEY (Royal Aircraft Establishment, Dynamics Laboratory, Bedford, England) Aeronautical Journal (ISSN 0001-9240), vol. 92, March 1988, p. 95-106. refs

A review is given of some recent research, mainly at low speeds. into the development of dynamic lift. Sudden movement of aerodynamic surfaces can generate dynamic lift due to the transient development of separated flow. These dynamic effects are large and well established for aerofoils. They are considered likely to be small for highly swept wings and negligible for slender wings, but there is little experimental evidence to support this inference. The dynamic lift might be increased if conventional sinusoidal motions can be replaced by appropriate periodic saw-tooth motions. The control of large-scale flow separations by rapid movements of aerodynamic surfaces requires further investigation to resolve some of the controversial issues raised in the review. Author

#### APPLICATION OF EFFICIENT ITERATION SCHEME AF2 TO COMPUTATIONS OF TRANSONIC FULL-POTENTIAL FLOWS **OVER WING-BODY COMBINATIONS**

MINGKE HUANG (Nanjing Aeronautical Institute, People's Republic Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Jan. 1988, p. A11-A18. In Chinese, with abstract in English. refs

The flow region around the wing-body combination is transformed by local Joukowski transformation into the one around a wing alone for the case with the body of circular cross section. The body-fitted 'O' mesh around the transformed wing alone is constructed for each grid section by numerical conformal mapping, and is then transformed back to form 3-D bodyfitted mesh around the given wing-body combination. The transonic flow computation is performed by the use of a conservative full-potential equation with exact boundary conditions and the efficient iteration scheme

in finite difference method AF2. It is shown that only a few changes are needed to expand the computer program for wing alone to cover wing-body combinations. The presented method is limited to the combinations which consist of the bodies of finite or infinite lengths with curved axes and circular cross sections, and the wing of arbitrary planform with finite wing tip.

Author

#### A88-38185# EXPERIMENTAL INVESTIGATION ON RIGID HOLLOW HEMISPHERICAL PARACHUTE MODEL IN ACCELERATING AND STEADY FLOW

QIXIANG LIAN (Beijing Institute of Aeronautics and Astronautics, People's Republic of China) and MINXUAN ZHOU (Nanjing, Hongguang Aero-Dropping Equipment Factory, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Jan. 1988, p. A84-A90. In Chinese, with abstract in English. refs

The flow around hollow hemisphere models was investigated in water channel by hydrogen bubble technique. The flow velocity distribution both in front of and behind the model was measured by hydrogen bubble time lines. It is close to the values estimated by the irrotational flow theory for the flow right after the start. As the starting vortex grew larger, the flow in the wake is quite different. A large reversed flow is induced behind the model. Hence, the apparent mass estimated by irrotational flow can only be at the beginning. It should be much larger as the starting vortex becomes larger. Sometimes a large vortex in front of model may be formed in the steady flow. This vortex is unstable and may cause side force and unstable motion to a parachute. This vortex can be reduced and even be eliminated by holes suitably placed on the model.

#### A88-38186#

#### LINEAR DYNAMICS OF SUPERSONIC INLET

YANSHEN GUAN, XIN YANG, and ZUO KU (Northwestern Polytechnical University, Xian, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Jan. 1988, p. A91-A96. In Chinese, with abstract in English. refs

This paper presents a linear mathematical model and method of digital simulation for supersonic inlet dynamics. A simplified steady-state mathematical model and a linear dynamic model of supersonic inlets are combined into an integral one. The latter can be used to calculate directly the steady-state characteristics and to simulate the linear dynamic behavior of both axisymmetrical and two-dimensional supersonic inlets under certain operating conditions. The simulated dynamic responses of a NASA 48 cm axisymmetrical and a NASA 2200 cm two-dimensional supersonic inlets are in good agreement with experimental data.

#### A88-38188#

## THE CHARACTERISTICS OF ASYMMETRIC VORTICES AND SIDE FORCES ON A SHARP-NOSED BODY WITH WING AND VERTICAL TAIL

NANQIAN CHEN (Beijing Institute of Aeronautics and Astronautics, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Feb. 1988, p. B11-B16. In Chinese, with abstract in English.

The variations of side force C(z) vs angles of attack alpha on the wing-body combination and wing-body-vertical tail combination are similar to that on the body-alone at high angles of attack with zero side-slip. They are also similar to that of C(z) vs alpha on the wing-body combination at high angles of attack with beta between -8 and +8 deg. Three kinds of strakes are found to be highly effective on alleviating asymmetric vortices, as well as induced side forces on the body, wing-body-vertical tail combinations with zero side-slip and high angles of attack.

Author

#### A88-38303#

IMPROVEMENTS ON ACCURACY AND EFFICIENCY FOR CALCULATION OF TRANSONIC VISCOUS FLOW AROUND AN AIRFOIL

YI-YUN WANG and TOSHI FUJIWARA (Nagoya University, Japan) Nagoya University, Faculty of Engineering, Memoirs (ISSN 0027-7657), vol. 39, no. 1, 1987, p. 180-193. refs

Several improvements to the procedure of calculating transonic flows around an airfoil are proposed. These include the use of the Beam-Warming implicit factorization scheme, the use of an LU-decomposition to avoid inverting block triangular matrices, and the use of local time step to reach a steady solution. The use of a mixed monlinear dissipation is shown to enhance shock resolution, while the bundary treatment of like-characteristics improve accuracy and reliability. To demonstrate the improvements, calculations are carried out for the RAE 2822 airfoil at Mach 0.75 and angle of attack 3.19 deg.

#### A88-38343

## FLOW ANALYSIS AROUND AIRCRAFT BY VISCOUS FLOW COMPUTATION

TADAYUKI TANIOKA, TAKESHI KAIDEN, JUNICHI MIYAKAWA, and MIHO SHIMIZU (Mitsubishi Heavy Industries, Ltd., Nagoya Aircraft Works, Japan) Mitsubishi Heavy Industries Technical Review (ISSN 0026-6817), vol. 25, Feb. 1988, p. 50-56. refs

Viscous flow computation CFD techniques numerically solve the Navier-Stokes equations on the basis of aircraft geometry boundary conditions. Novel digital simulations employing these methods are expected to be fully equivalent to wind tunnel tests. Attention is presently given to the preprocessing, flow computation, and data-display phases of these CFD methods, for the cases of a transonic airfoil, a transonic airfoil with aileron, interference between lifting surfaces, and a three-dimensional wing-body configuration.

A88-38376\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

## NUMERICAL STUDY OF THE SKIN FRICTION ON A SPHEROID AT INCIDENCE

M. ROSENFELD, ED. (NASA, Ames Research Center, Moffett Field, CA; Technion - Israel Institute of Technology, Haifa), M. ISRAELI, ED., and M. WOLFSHTEIN, ED. (Technion - Israel Institute of Technology, Haifa) (Israel Annual Conference on Aviation and Astronautics, 28th, Tel Aviv and Haifa, Israel, Feb. 19, 20, 1986, Collection of Papers, p. 171-180) AIAA Journal (ISSN 0001-1452), vol. 26, Feb. 1988, p. 129-136. Research supported by the Stiftung Volkswagenwerk. Previously cited in issue 14, p. 2104, Accession no. A87-35020. refs

## A88-38377\*# Notre Dame Univ., Ind. VISUALIZATION AND WAKE SURVEYS OF VORTICAL FLOW OVER A DELTA WING

F. M. PAYNE, T. T. NG, R. C. NELSON (Notre Dame, University, IN), and L. B. SCHIFF (NASA, Ames Research Center, Moffett Field, CA) AIAA Journal (ISSN 0001-1452), vol. 26, Feb. 1988, p. 137-143. Research supported by the University of Notre Dame. Previously cited in issue 07, p. 833, Accession no. A86-19817.

(Contract NAG2-258)

**A88-38775\*** National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

## THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE SLOTTED-WALL FLOW FIELD IN A TRANSONIC WIND TUNNEL

JOEL L. EVERHART (NASA, Langley Research Center, Hampton, VA) SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, Oct. 5-8, 1987. 20 p. refs (SAE PAPER 871757)

The flow in the vicinity of a longitudinally slotted wind-tunnel wall is theoretically analyzed, and equations describing the pressure drop across the wall are derived. The ideal form of the slotted-wall boundary condition is shown to effectively model the wall pressure drop upstream of the point of maximum model thickness providing that a zero-shift correction to the reference pressure is included in the analysis. The wall-pressure drop equations can be linearized

by subtracting the tunnel-empty boundary condition. Good correlation is obtained between experimental and theoretical values for variations in Mach number and angle of attack.

R.R.

#### A88-38847

ANALYTICAL STUDY OF FRICTION AND HEAT TRANSFER IN THE VICINITY OF A THREE-DIMENSIONAL CRITICAL POINT AT LOW AND MODERATE REYNOLDS NUMBERS [ANALITICHESKOE ISSLEDOVANIE TRENIIA I TEPLOOBMENA V OKRESTNOSTI TREKHMERNOI KRITICHESKOI TOCHKI PRI MALYKH I UMERNNYKH CHISLAKH REINOL'DSA]

I. G. BRYKINA and V. V. RUSAKOV Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza (ISSN 0568-5281), Mar.-Apr. 1988, p. 143-150. In Russian. refs

Hypersonic three-dimensional flow of a viscous gas past blunt bodies at low and moderate Reynolds numbers is investigated analytically with allowance for slip effects and a temperature discontinuity at the surface. Equations of a three-dimensional viscous shock layer are solved by the integral method of successive approximations and by the finite difference method near the critical point. An analytical solution to the problem is obtained to a first approximation. An analysis of the solution yields a simple formula which reduces the calculation of heat flux toward a three-dimensional critical point to the calculation of heat flux toward an axisymmetrical critical point.

A88-38925\* Analytical Services and Materials, Inc., Hampton,

#### BOUNDARY-LAYER STABILITY ANALYSIS OF NLF AND LFC EXPERIMENTAL DATA AT SUBSONIC AND TRANSONIC SPEEDS

SCOTT A. BERRY (Analytical Services and Materials, Inc., Hampton, VA), J. RAY DAGENHART, ROBERT B. YEATON (NASA, Langley Research Center, Hampton, VA), and JEFFREY K. VIKEN (Complere, Inc., Hampton, VA) SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, Oct. 5-8, 1987. 12 p. refs (SAE PAPER 871859)

NASA-Lewis has conducted wind tunnel experiments to ascertain the effectiveness of state-of-the-art in natural laminar flow (NLF) and LFC airfoils for subsonic and transonic speeds, such as the NLF(1)-0414F and the SCLFC(1)-0513F. Attention is given to the effects of Tollmien-Schlichting (TS) and/or crossflow linear mechanisms amplifying small disturbances to generate turbulence. It is found that the incompressible TS transitional n-factors were generally in the 9-12 range, in agreement with earlier correlation studies; the TS instability was the dominant instability mode on a swept-planform LFC airfoil over the entire range of test conditions.

A88-38950\* National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

THEORETICAL INVESTIGATIONS, AND CORRELATIVE STUDIES FOR NLF, HLFC, AND LFC SWEPT WINGS AT SUBSONIC, TRANSONIC AND SUPERSONIC SPEEDS

S. H. GORADIA, P. J. BOBBITT, J. C. FERRIS, and W. D. HARVEY (NASA, Langley Research Center, Hampton, VA) SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, Oct. 5-8, 1987. 24 p. refs
(SAE PAPER 871861)

Attention is given to the results of theory/experiment-correlation studies for natural laminar flow, LFC, and hybrid-LFC airfoils at subsonic and supersonic Mach numbers. The method of characteristics, integral compressible boundary layer methods for infinitely swept wings, and a method for prediction of separating turbulent boundary layer characteristics. The integral boundary layer methods are found to be successful at predicting both transonic and supersonic transition phenomena. Computations for wings with 0-50 deg sweep angle, Reynolds number range of 1-30 million, and with and without LFC, are in good agreement with experimental data.

#### A88-38976#

### PIEZO-ELECTRIC FOILS AS A MEANS OF SENSING UNSTEADY SURFACE FORCES ON FLOW-AROUND BODIES

W. NITSCHE, P. MIROW (Berlin, Technische Universitaet, Federal Republic of Germany), and J. SZODRUCH (Messerschmitt-Boelkow-Blohm GmbH, Bremen, Federal Republic of Germany) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 6-2-1 to 6-2-7. Research supported by the Technische Universitaet Berlin, BMFT, and DFG. refs

The experimental determination of steady as well as of unsteady surface-forces on flow-around bodies belongs to the elementary problems in experimental fluid dynamics, e.g. in experimental aircraft aerodynamics. Up to now, experiments on unsteady forces such as pressure or shear fluctuations are performed by means of special plug-like probes (e.g. miniature pressure transducers). An alternative and attractive technique of monitoring unsteady surface forces has become possible through the development of piezoelectric foils. With this novel type of sensor, which can be simply glued on a surface, the piezoelectric effect of polarized plastic foils is used to register time dependent pressure or shear loads on flow-around bodies. First of all, the paper concentrates on the fundamentals of this new measuring technique. Furthermore, some practical applications in experimental aerodynamics are outlined.

#### A88-38984#

## COMPUTATIONAL STUDY OF THE UNSTEADY FLOW DUE TO WAKES PASSING THROUGH A CHANNEL

B. SCHOENUNG, R. R. MANKBADI, and W. RODI (Karlsruhe, Universitaet, Federal Republic of Germany) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 8-1-1 to 8-1-6. Research supported by the Forschungsvereinigung Verbrennungskraftmaschinen. refs

The flow in and the heat transfer to turbine cascades are influenced strongly by rotor-stator interaction causing wakes from the preceding row to pass through the cascade channel. Predictions of this unsteady flow are presented for the idealized case of a plane channel with the wakes generated by cylinders moving past the inlet plane. The calculations are obtained with an unsteady finite-volume method employing the k-epsilon turbulence model. The calculation procedure is verified first for developing steady channel flow and is then applied to the unsteady passing wake situation for various moving cylinder-channel configurations. The results show that the passing wakes cause much stronger velocity fluctuations than would be due to turbulence.

### A88-38985\*# Stanford Univ., Calif. PROPERTIES OF A HALF-DELTA WING VORTEX

RABINDRA D. MEHTA (Stanford University, CA) and ELIZABETH R. CANTWELL (NASA, Ames Research Center, Moffett Field, CA) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 8-3-1 to 8-3-6. refs (Contract NCC2-294)

The mean flow and turbulence structure of a single longitudinal vortex generated by a half-delta wing placed at a small angle of attack were investigated. Particular consideration was given to the near-field properties of the generator in order to establish the role of the generator wake in the initial rolling-up of the vortex, as well as to the far-field properties so that the approach to equilibrium could be studied. Measurements were made on fine cross-plane grids at seven streamwise locations using hot cross wires. The results show that the point of maximum vorticity and the generator wake do not merge until a streamwise distance equivalent to three generator heights is reached. Comparison with previous data on vortices produced by double-branched generators confirmed that the present vortex had achieved a fully developed state, and at a relatively short streamwise distance.

#### A88-38986#

#### LDV MEASUREMENTS ON IMPINGING TWIN-JET FOUNTAIN FLOWS WITH A SIMULATED FUSELAGE UNDERSURFACE

K. R. SARIPALLI (McDonnell Douglas Research Laboratories, Saint IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings, University Park, PA, Pennsylvania State University, 1987, p. 8-4-1 to 8-4-8. refs

This paper describes the characteristics of an axisymmetric twin-jet fountain flow in the presence of a simulated fuselage undersurface which simulated the twin-jet configuration of an AV-8B VTOL aircraft. The experiments included flow visualization studies and LDV measurements. Two distinct flow regimes were identified: (1) an isolated fountain region where both the mean velocity and turbulence quantities exhibit self-similarity, and the spread and decay of the fountain are linear; and (2) an interactive fountain region where the upwash flow interacts with the fuselage undersurface and the source jets, thus forming strong recirculation zones.

#### A88-38987#

#### MEASUREMENTS OF TURBULENT FLOW BEHIND A WING-BODY JUNCTION

OKTAY OZGAN and SEMIH OLCMEN (Istanbul Technical University, Turkey) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 8-5-1 to 8-5-5.

An experimental investigation of the turbulent shear flow behind a wing-flat plate junction is reported. Presented data include skin-friction lines and coefficient, static pressure coefficient and mean velocity components. A secondary separation line and a single tornado vortex were observed on the flat plate downstream of the wing. Velocity measurements revealed a complex vortical flow structure which was consistent with a proposed mean streamline pattern in the cross-flow plane.

#### A88-38988#

#### TIME-DEPENDENT STRUCTURE IN WING-BODY JUNCTION **FLOWS**

WILLIAM J. DEVENPORT and R. L. SIMPSON (Virginia Polytechnic Institute and State University, Blacksburg) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 8-6-1 to 8-6-8. refs (Contract N60921-83-C-A165-B02)

The time-dependent and time averaged features of a wing-body junction flow formed around a cylindrical wing with a 1.5:1 elliptical nose and NACA 0020 tail are being studied. In this paper, velocity and skin friction measurements made in the nose region are presented and discussed. These measurements show that a coherent junction vortex is a feature of both the instantaneous and time-mean flows. Away from the wing fluctuations in the instantaneous size and position of this vortex produce bimodal (double-peaked) histograms of velocity fluctuations. Adjacent to the wing this vortex appears to be associated with a region of Author laminarescent flow.

#### A88-39000#

#### MEASUREMENTS IN A THREE-DIMENSIONAL TURBULENT **BOUNDARY-LAYER**

OKTAY OZCAN (Istanbul Technical University, Turkey) Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 11-1-1 to 11-1-6. refs

An experimental study of a three-dimensional, pressure-driven, attached turbulent boundary-layer flow was made at Mach 0.4. Both the mean velocities and the full Reynolds stress tensor were measured simultaneously by a three-component LDA system. Favorable and adverse streamwise and azimuthal pressure gradients existed on the swept-bump model which simulated the highly three-dimensional boundary-layer flow on a swept wing. The streamwise distance measured from the bump leading edge was observed to be a correlation parameter for all mean flow quantities. Several assumptions used for turbulence modeling three-dimensional boundary-layers were checked for their validity Author in this flow.

A88-39011\*# Imperial Coll. of Science and Technology, London (England).

#### FLOW IN OUT-OF-PLANE DOUBLE S-BENDS

M. C. SCHMIDT, J. H. WHITELAW (Imperial College of Science and Technology, London, England), and M. YIANNESKIS (King's College, London, England) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 13-3-1 to 13-3-6. refs

(Contract NAGW-747)

An experimental investigation of developing flows through a combination of out-of-plane S-bend ducts was conducted to gain insight into the redirection of flow in geometries similar to those encountered in practical aircraft wing-root intake ducts. The present double S-bend was fabricated by placing previously investigated S-ducts and S-diffusers in series and with perpendicular planes of symmetry. Laser-Doppler anemometry was employed to measure the three components of mean velocity, the corresponding rms quantities, and Reynolds stresses in the rectangular cross-section ducts. Due to limited optical access, only two mean and rms velocity components were resolved in the circular cross-section ducts. The velocity measurements were complemented by wall static pressure measurements. The data indicates that the flows at the exit are complex and asymmetric. Secondary flows generated by the pressure field in the first S-duct are complemented or counteracted by the secondary flows produced by the area expansion and the curvature of the S-diffuser. The results indicate the dominance of the inlet conditions and geometry upon the development of secondary flows and demonstrate that the flows are predominantly pressure-controlled. The pressure distribution caused by the duct geometry determines the direction and magnitude of the bulk flow while the turbulence dictates the mixing characteristics and profiles in the near wall region.

#### A88-39017#

#### EXPERIMENTAL AND NUMERICAL ANALYSIS OF THE FORMATION AND EVOLUTION OF STREAMWISE VORTICES IN THE PLANE WAKE BEHIND A FLAT PLATE

E. MEIBURG (Stanford University, CA) and J. C. LASHERAS (Southern California, University, Los Angeles, CA) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 16-1-1 to 16-1-6. Research supported by the U.S.-Spain Joint Committee for Scientific and Technological Cooperation.

The three-dimensional structure of the vorticity field in a plane wake behind a flat plate is studied both experimentally and numerically. It is shown that under the effect of perturbations initially distributed periodically along the span, the redistribution, reorientation, and stretching of the vorticity in the wake leads to the formation of counter-rotating pairs of streamwise vortices. These streamwise vortices exhibit a lambda-shaped structure and are oriented along the direction of the principal plane of the positive strain field existing in the braids connecting consecutive Karman vortices of opposite sign.

#### A88-39023\*# Princeton Univ., N. J.

#### DETECTION OF LARGE-SCALE ORGANIZED MOTIONS IN A **TURBULENT BOUNDARY LAYER**

E. M. FERNANDO, E. F. SPINA, J. F. DONOVAN, and A. J. SMITS (Princeton University, NJ) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 16-8-1 to 16-8-6. refs

(Contract AF-AFOSR-85-0126; NAG1-545)

This paper presents and discusses experimental data from an investigation of organized motions in a supersonic turbulent boundary layer. Conditional sampling of crossed-wire and multiple normal-wire signals is performed. A comparison is made between

events detected using the VITA conditional sampling technique and those found by thresholding the UV signal. Based on this comparison, limitations of the VITA technique are discussed. The conditional sampling results indicate that most organized motions are consistent with hairpin vortices.

A88-39030#

## THE CALCULATION OF THE FLOW THROUGH A TWO-DIMENSIONAL FAIRED DIFFUSER

W. P. JONES (Imperial College of Science and Technology, London, England) and A. MANNERS (Rolls-Royce, PLC, Derby, England) IN: Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 17-7-1 to 17-7-5. refs

A Reynolds stress transport equation model and the k-epsilon turbulence model have been applied to the calculation of the flow through an annular faired gas turbine diffuser. The results clearly show the superiority of the transport equation model which accurately reproduces the observed features of the flow. These include the influences of curvature associated with the inlet and outlet bends, the recovery from the adverse pressure gradient of the diffusing section and the asymmetric velocity profile in the setting length downstream of the diffuser. None of these is adequately represented by the k-epsilon model. In addition, the velocity profiles predicted by the model are in broad agreement with those measured whereas, with the k-epsilon model, large discrepancies arise.

#### A88-39278

## COMPARISON OF EULER AND NAVIER-STOKES SOLUTIONS FOR VORTEX FLOW OVER A DELTA WING

A. RIZZI (Flygtekniska Forsoksanstalten, Bromma; Kungliga Tekniska Hogskolan, Stockholm, Sweden) and B. MUELLER (Flygtekniska Forsoksanstalten, Bromma, Sweden) Aeronautical Journal (ISSN 0001-9240), vol. 92, April 1988, p. 145-153. Research supported by the Styrelsen for Teknisk Utveckling, U.S. Navy, and NSF. refs

A numerical method has been developed recently to solve the Navier-Stokes equations for laminar compressible flow around delta wings. A large-scale Navier-Stokes solution on a mesh of 129 x 49 x 65 points for transonic freestream Mach flow of 0.85. alpha = 10 deg and freestream Reynolds number of 2.38 million around a 65 deg swept delta wing with round leading edge is presented and compared with a correspondingly large-scale Euler solution. The viscous results reveal the presence of primary, secondary, and even tertiary vortices. The starting location of the primary vortex is seen to be quite different in the two solutions. In the viscous solution it starts at the wing apex, but in the Euler results it starts about one quarter chord downstream. The secondary separations are also different, due to the up-lifting of the boundary layer in the viscous results, but to a cross-flow shock in the Euler computation. Comparison with experiment shows that the interaction between the primary and secondary vortices in the Navier-Stokes computation is obtained correctly and that these results are a more realistic simulation than the one given by the Euler equations.

#### A88-39279

## PREDICTION OF VORTEX LIFT OF NON-PLANAR WINGS BY THE LEADING-EDGE SUCTION ANALOGY

B. C. HARDY and S. P. FIDDES (Royal Aircraft Establishment, Farnborough, England) Aeronautical Journal (ISSN 0001-9240), vol. 92, April 1988, p. 154-164. refs

A three-dimensional panel method has been used to calculate edge-suction forces for thin sharp-edged wings in incompressible flow. The suction forces have been used to estimate the vortex lift on the wings by means of the leading-edge suction analogy due to Polhamus. The results for planar wings are in acceptable agreement with other methods based on the suction analogy. A limited comparison with results from experiments for nonplanar wings revealed good prediction of lift and drag increments associated with the deflection of leading and trailing edge flaps

for 'conventional' wings of high sweep, but only moderate agreement for a grossly nonplanar configuration.

Author

#### A88-39488

## COMPUTATION OF CASCADE FLOW USING A FINITE-FLUX-ELEMENT METHOD (BERECHNUNG DER GITTERSTROEMUNG MIT HILFE EINES FINITEN-FLUSS-ELEMENTE-VERFAHRENS)

S. GRASWALD (Muenchen, Technische Universitaet, Munich, Federal Republic of Germany) Zeitschrift fuer Flugwissenschaften und Weltraumforschung (ISSN 0342-068X), vol. 12, Mar.-Apr. 1988, p. 111-115. In German. refs

The subdomain FEM procedure developed by Lucchi (1979) and Weber et al. (1984) to solve the conservative full potential equations for transonic plane cascade flow is extended and refined to treat axisymmetric stream surfaces. Particular attention is given to the basic equations, the introduction of the potential, the computational domain and control volume, the form functions, the treatment of density, and the boundary conditions. The numerical implementation of the method is briefly characterized, and typical results are presented in graphs. The present technique permits direct computation of blade profiles without the need for projection onto cylindrical surfaces.

A88-39511\* Lockheed Missiles and Space Co., Sunnyvale, Calif.

### FLUID MECHANICS OF DYNAMIC STALL. I - UNSTEADY FLOW CONCEPTS

L. E. ERICSSON and J. P. REDING (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA) Journal of Fluids and Structures (ISSN 0889-9746), vol. 2, Jan. 1988, p. 1-33. refs (Contract NAS1-7999; NAS1-9987)

Advanced military aircraft 'supermaneuverability' requirements entail the sustained operation of airfoils at stalled flow conditions. The present work addresses the effects of separated flow on vehicle dynamics; an analytic method is presented which employs static experimental data to predict the separated flow effect on incompressible unsteady aerodynamics. The key parameters in the analytic relationship between steady and nonsteady aerodynamics are the time-lag before a change of flow conditions can affect the separation-induced aerodynamic loads, the accelerated flow effect, and the moving wall effect.

A88-39512\* Lockheed Missiles and Space Co., Sunnyvale, Calif.

## FLUID MECHANICS OF DYNAMIC STALL. II - PREDICTION OF FULL SCALE CHARACTERISTICS

L. E. ERICSSON and J. P. REDING (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA) Journal of Fluids and Structures (ISSN 0889-9746), vol. 2, March 1988, p. 113-143. refs (Contract NAS1-7999; NAS1-9987)

Analytical extrapolations are made from experimental subscale dynamics to predict full scale characteristics of dynamic stall. The method proceeds by establishing analytic relationships between dynamic and static aerodynamic characteristics induced by viscous flow effects. The method is then validated by predicting dynamic test results on the basis of corresponding static test data obtained at the same subscale flow conditions, and the effect of Reynolds number on the static aerodynamic characteristics are determined from subscale to full scale flow conditions.

O.C.

#### A88-39623

## EXPERIMENTAL STUDY OF A SUPERSONIC TURBULENT BOUNDARY LAYER USING A LASER DOPPLER ANEMOMETER

MAX ELENA and JEAN-PAUL LACHARME (Aix-Marseille II, Universite, Marseille, France) Journal de Mecanique Theorique et Appliquee (ISSN 0750-7240), vol. 7, no. 2, 1988, p. 175-190. DRET-supported research. refs

A two-component LDA is used to experimentally study a quasi-equilibrium supersonic turbulent boundary layer, and the measured characteristics of turbulence are compared to hot-wire measurements. Measurements are obtained of velocity fluctuations,

Reynolds tangential stresses, skewness and flatness factors, and the intermittency factor, at a freestream Mach number of 2.3. Boundary layer measurements are shown to agree with boundary layer data taking compressibility effects into account. The effect of the injection of light-scattering particles on the LDA results is investigated.

#### A88-39952

## OBSERVATION OF THREE-DIMENSIONAL 'SEPARATION' IN SHOCK WAVE TURBULENT BOUNDARY LAYER INTERACTIONS

S. M. BOGDONOFF (Princeton University, NJ) IN: Boundary-layer separation; Proceedings of the IUTAM Symposium, London, England, Aug. 26-28, 1986. Berlin and New York, Springer-Verlag, 1987, p. 37-55. refs

(Contract F49620-84-C-0086)

Analyses have been conducted of specific two-dimensional and highly swept three-dimensional shock wave and turbulent boundary layer interactions. It is found that three-dimensional flows are drastically different from classical two-dimensional flows; these differences extend to scales, pressure gradients, degree of unsteadiness, and computability. The characterization of phenomena as being of 'separation' is not realistic in three-dimensions. A concept of 'vorticity rearrangement is proposed to describe the physics of three-dimensional interaction.

#### A88-39967

### SEPARATION AND REATTACHMENT NEAR THELEADING EDGE OF A THIN WING

TUNCER CEBECI, KALLE KAUPS, and A. A. KHATTAB (Douglas Aircraft Co., Long Beach, CA) IN: Boundary-layer separation; Proceedings of the IUTAM Symposium, London, England, Aug. 26-28, 1986. Berlin and New York, Springer-Verlag, 1987, p. 313-330. refs

(Contract F49620-84-C-0007)

An interactive boundary-layer procedure based on a quasi-three-dimensional approximation is used to calculate separation and reattachment near the leading-edge of a thin wing. Results for a given sweep angle show that, as in two-dimensional flows, reverse flow solutions exist only for a limited range of angles of attack above the critical angle at which the non-interactive boundary layer separates. The solutions for the upper branch behave in the same manner as those predicted by the triple-deck theory for marginal separation in two-dimensional flows. The existence of solutions for the lower branch remains to be investigated.

#### A88-39970

## EXPERIMENTAL INVESTIGATION OF TOPOLOGICAL STRUCTURES IN THREE-DIMENSIONAL SEPARATED FLOW

H. BIPPES (DFVLR, Institut fuer experimentelle Stroemungsmechanik, Goettingen, Federal Republic of Germany) IN: Boundary-layer separation; Proceedings of the IUTAM Symposium, London, England, Aug. 26-28, 1986. Berlin and New York, Springer-Verlag, 1987, p. 379-381.

A treatment is presented for that class of three-dimensional separated flows where a system of vortices develops with vortex filaments that are not everywhere aligned to the oncoming flow, so that unsteady flow areas originate. This type of separation appears on a hemisphere cylinder at incidence. An attempt is made to detect and classify the possible topological structures of the class of three-dimensional separated flows thus defined.

O.C.

#### A88-40311

### AERODYNAMICS OF SUPERSONIC SHAPES [AERODINAMIKA SVERKHZVUKOVYKH FORM]

ALEKSANDR IVANOVICH SHVETS Moscow, Izdatel'stvo Moskovskogo Universiteta, 1987, 208 p. In Russian. refs

Problems in the aerodynamics of supersonic shapes are examined with reference to recent theoretical and experimental research related to minimum-drag bodies. In particular, attention is given to inverse problems in gas dynamics, methods for

calculating flow past bodies of star-like configurations, and principles of the design of star-shaped structures. The discussion also covers wind tunnel test data, physical models of flows, and methods for calculating real structures with allowance for edge bluntness, friction, and heat transfer.

V.L.

#### A88-40314

## FACTORS AFFECTING THE TEMPERATURE STATE OF THE BLADING OF HIGH-TEMPERATURE TURBINES [FAKTORY, VLIIAIUSHCHIE NA TEMPERATURNOE SOSTOIANIE LOPATOCHNYKH APPARATOV VYSOKOTEMPERATURNYKH TURBIN]

L. M. ZYSINA-MOLOZHEN (Nauchno-Proizvodstvennoe Ob'edinenie, TsKTI, Leningrad, USSR) Promyshlennaia Teplotekhnika (ISSN 0204-3602), vol. 10, no. 2, 1988, p. 12-24. In Russian. refs

Recent work concerned with flow mechanisms, turbulence structure, and local heat transfer coefficients in the interprofile passages of turbine blading is reviewed. Particular attention is given to two groups of papers: those dealing with cascades of short blades and the effect of secondary flows on the heat transfer from the profiles and end walls and those dealing with the effect of the guide and rotor blades on flow and heat transfer. The factors to be considered in evaluating the thermal stressed state of blades are identified.

#### A88-40375#

#### HEAT FLUX ON THE SURFACE OF A WEDGE IN MACH REFLECTION AND REGULAR REFLECTION OF SHOCK WAVES

MASANORI HAYASHI, SHIGERU ASO, YOSHIHARU TANAHASHI, and AKIRA YAMASHITA Kyushu University, Technology Reports (ISSN 0023-2718), vol. 61, Jan. 1988, p. 59-65. In Japanese, with abstract in English. refs

Measurements of transient temperature and pressure rise on a surface of wedge in a shock tube have been carried out for the case where the incident oblique shock waves on the surface reflect under the conditions of shock Mach numbers 1.34-2.75, with wedge angles of 35.0-48.0 degrees. The heat flux on the surface has been calculated by using the temperature rise. It is known that there are four patterns for the shock reflections. In this paper, these shock reflection patterns have been visualized by the Schlieren method. Finally, it is shown that each flow pattern exhibits characteristic changes of the surface temperature, heat flux and pressure rise with time, and these variations are influenced by the slipstream.

#### A88-40421#

## UNSTEADY AERODYNAMIC HEATING PHENOMENA IN THE INTERACTION OF SHOCK WAVE/TURBULENT BOUNDARY

MASANORI HAYASHI, SHIGERU ASO (Kyushu University, Fukuoka, Japan), and ANZHONG TAN Kyushu University, Faculty of Engineering, Memoirs (ISSN 0023-6160), vol. 47, Dec. 1987, p. 231-239. refs

Fluctuations of heat transfer have been measured in the regions of interaction between oblique shock waves and turbulent boundary layers. A new type of heat transfer rate gauge with high spatial resolution and fast response developed in the laboratory was used for the measurements of heat transfer rates. Results are compared with the wall pressure fluctuation measurements performed under the same test conditions. Experiments were made at a nominal Mach number of 4, wall temperature condition of 0.56, and Reynolds number of 1,26 x 10 to the 7th based on the distance from the flat plate leading edge. When the boundary layer is unseparated, fluctuations of heat transfer get strong near the impinging point of the incident shock; however no intermittency phenomena are observed. When the boundary layer is separated, significant fluctuations of heat transfer are observed throughout the interaction region. Near the separation and the reattachment point, the fluctuations are particularly strong, and near the separation point intermittency of heat transfer is observed.

Author

**A88-40601\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

### FLOW VISUALIZATION AND PRESSURE DISTRIBUTIONS FOR AN ALL-BODY HYPERSONIC AIRCRAFT

WILLIAM K. LOCKMAN, SCOTT L. LAWRENCE (NASA, Ames Research Center, Moffett Field, CA), and JOSEPH W. CLEARY (Eloret Institute, Sunnyvale, CA) USAF, National Aero-Space Plane Technology Symposium, 4th, Monterey, CA, Feb. 17-19, 1988, Paper. 27 p. refs (Contract NCC2-416)

A CFD code-validation effort has been conducted at the NASA-Ames 3.5-ft hypersonic wind tunnel, using a generic, 'all-body' hypersonic aircraft configuration model. The CFD methods to be validated encompass approximate inviscid ones and the upwind parabolized Navier-Stokes solver code. Flow visualizations and pressure distributions are obtained for the cases of zero and 15 deg angles of attack. A complex leeward flow is observed at angle-of-attack with crossflow separation and vortices, and significant changes are noted in the transition from the forebody's conical to the afterbody's nonconical flows.

#### A88-40701

## AIAA APPLIED AERODYNAMICS CONFERENCE, 6TH, WILLIAMSBURG, VA, JUNE 6-8, 1988, TECHNICAL PAPERS

Conference sponsored by AIAA. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, 704 p. For individual items see A88-40702 to A88-40769.

The present conference on applied aerodynamics discusses the flowfield for the propeller disks of a twin-pusher canard configuration, the effects of canard-wing flowfield interactions on longitudinal stability and potential deep-stall trim, the progress of wing vortex flows to vortex breakdown, flow visualization by IR imaging, wind tunnel investigation of wing-in-ground effects, three-dimensional windmill surface pressure calculations, the base drag of highly maneuvering nonthrusting missiles, riblet drag reduction at flight conditions, and calculations of hypersonic transitional flow over cones. Also discussed are the roll characteristics of finned projectiles, the design of low Reynolds number airfoils, a comparative study of vortex structures, three-dimensional hypersonic nonequilibrium flows at large angles-of-attack, the analysis of wing rock due to forebody vortices, and the influence of small surface discontinuities in turbulent boundary layers.

#### A88-40702#

## THE NUMERICAL SIMULATION OF THE NAVIER-STOKES EQUATIONS FOR AN F-16 CONFIGURATION

GARY W. HUBAND, DONALD P. RIZZETTA, and JOSEPH J. S. SHANG (USAF, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 1-8. refs

(AIAA PAPER 88-2507)

A numerical solution is presented for the steady-state flow over an F-16A aircraft configuration at a freestream Mach number of 1.2, a Reynold's number of 12.75 million, and an angle-of-attack of six degrees. The three-dimensional Navier-Stokes equations in mass-averaged variables were numerically integrated using the MacCormack (1969) explicit algorithm with an algebraic turbulence model to provide closure of the system of equations. The grid structure, boundary conditions, turbulence model, and solution procedure are discussed in detail for this complex aircraft geometry. The solution is then compared to experimental results in terms of surface pressure coefficients with reasonable agreement. Finally, details of the flow are discussed, such as the strake vortex and the wing vortex structures.

#### A88-40705#

## ON A LEAST-ENERGY HYPOTHESIS FOR THE WAKE OF AXISYMMETRIC BODIES WITH TURBULENT SEPARATION - PRESSURE-DISTRIBUTION PREDICTION

FABIO R. GOLDSCHMIED IN: AIAA Applied Aerodynamics

Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 27-39. refs (AIAA PAPER 88-2513)

It is presently hypothesized that the free-wake development, in such axisymmetric low-speed bodies with turbulent flow separation as Rankine bodies with convex or conical tails, must be such as to minimize energy and momentum losses. A hyperbolic contour is assumed for constant-momentum wake 'displacement afterbodies'; the momentum loss at any axial wake location is given by the Young equation, and the boundary layer-over-body and 'displacement aftbody' are computed by the E7ES algorithm. It is found that the addition of the 'aftbody' to the Rankine body would eliminate the turbulent free wake and generate a steady attached wake.

#### A88-40708#

### APPLICATIONS OF AN EULER AERODYNAMIC METHOD TO FREE-VORTEX FLOW SIMULATION

P. RAJ, J. M. KEEN, and S. W. SINGER (Lockheed Aeronautical Systems Co., Burbank, CA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 58-72. Research supported by the Lockheed Aeronautical Systems Co. refs

(Contract F33615-84-C-3005)

(AIAA PAPER 88-2517)

A Three-dimensional Euler Aerodynamic Method (TEAM) is used to simulate the interaction of free vortices with lifting surfaces. The free vortices may form due to flow separation along sharp leading edges of slender, swept wings at moderate to high angles of attack or be shed in the wake behind canards or wings. Computed results for a 74-deg delta wing, a 75/62-deg double-delta wing-body, and a canard-wing-body configuration are correlated with experimental data to evaluate TEAM's capabilities. In all cases, the flow is impulsively started and the vortices are automatically captured. Sensitivity of the computed solutions to the treatment of numerical dissipation needed to augment TEAM's cell-centered finite-volume algorithm is investigated. Also, the effect of grid density on computations is shown. The results provide an added measure of confidence in TEAM's abilities in simulating the free-vortex flows, and also point out some of its limitations.

Author

#### A88-40709#

## WING VORTEX-FLOWS UP INTO VORTEX BREAKDOWN - A NUMERICAL SIMULATION

STEPHAN M. HITZEL (Dornier GmbH, Friedrichshafen, Federal Republic of Germany) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 73-83. Research sponsored by the Bundesministerium der Verteidigung. refs (AIAA PAPER 88-2518)

Leading edge vortex flows, which may dominate the aerodynamics of future military aircraft as well as some civil transports, can be exploited through control of the currently troublesome vortex-breakdown phenomenon. The interaction of shock systems and vortex flows at supersonic speeds will also present important problems that must be anticipated theoretically and treated experimentally. Attention is presently given to the solution of the time-dependent Euler equations in conservation form by means of an explicit finite-volume approach, using such accelerating features as local time-stepping, a multigrid strategy, and enthalpy forcing.

#### A88-40712#

## FOURTH-ORDER ACCURATE CALCULATIONS OF THE 3-D COMPRESSIBLE BOUNDARY LAYERS ON AEROSPACE CONFIGURATIONS

SAMIR F. RADWAN (Alexandria University, Egypt) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June

6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 110-120. refs (AIAA PAPER 88-2522)

A fourth-order accurate finite-difference procedure is introduced to compute the compressible viscous flows over configurations with aerodyamic interest, in particular, fuselage-type and wing-type configurations. The first-order 3-D compressible boundary layer equations are written in nonorthogonal surface oriented coordinates and are solved in transformed coordinates. Two-point compact scheme with a fourth-order accuracy is used to solve the governing equations because of its high accuracy or its short computing time. The accuracy of the present method has been checked by computing well-documented test cases. Having done that, the subsonic viscous flowfields of a prolate spheroid and swept wing are computed. Their inviscid flow solutions are generated numerically by solving surface Euler equations. It is found that the present method is stable, efficient, and with a fourth-order accuracy. Therefore, it is recommended to use the present method in the stability analysis of laminar flows or in the viscous/inviscid interacting procedures.

#### A88-40714# FLOW PAST TWO-DIMENSIONAL RIBBON PARACHUTE MODELS

FUMIYUKI TAKAHASHI and HIROSHI HIGUCHI (Minnesota, University, Minneapolis) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 129-137. Research supported by Sandia National Laboratories. refs (AIAA PAPER 88-2524)

Aerodynamic characteristics of two-dimensional, slotted bluff bodies were experimentally investigated. Flow visualizations, base pressure measurements, mean velocity vector measurements, and drag force measurements were conducted to analyze effects of spacing ratio (i.e. porosity), curvature, and vent. Low porosity model configurations produced stable near-wake patterns with enhanced vortex sheddings downstream. Model curvature reduced drag forces and weakened the vortex sheddings. Stabilizing effect of curvature on the near-wake patterns was also found. A vent combined with large model curvature was found to control drag force effectively in addition to suppressing the vortex sheddings.

Author

## A88-40716# WIND TUNNEL INVESTIGATION OF WING-IN-GROUND FFFFCTS

M. D. CHAWLA (USAF, Flight Dynamics Laboratory, Wright-Patterson AFB, OH), L. C. EDWARDS, and M. E. FRANKE (USAF, Institute of Technology, Wright-Patterson AFB, OH) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 147-153. (AIAA PAPER 88-2527)

Wing-in-ground (WIG) effects from a wind tunnel study of a NACA 4415-airfoil-profile wing model with an aspect ratio of 2.33 are described. The wing model contains a 20-percent-chord, full-span adjustable flap and removable end and center plates. Ground boards are used in the wind tunnel to simulate the ground. In this study the ground effects are expressed as variations to the aerodynamic coefficients (lift and drag) and lift-to-drag ratio. The ground effects are described in terms of angle of attack, flap angle, wing height above ground, and use and size of end and center plates. It is shown that ground effects are diminished as the wing height from the ground is increased.

## A88-40717# EXPERIMENTAL AND ANALYTICAL AERODYNAMICS OF AN ADVANCED ROTOR IN HOVER

R. M. HODGES, JR., G. J. CARLIN, JR., and L. DADONE (Boeing Helicopters, Philadelphia, PA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical

Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 154-159. refs (AIAA PAPER 88-2530)

This paper deals with helicopter rotor hover performance and blade pressure data taken at the Duits Nederlandse Wind Tunnel (DNW) during the summer of 1986 and with correlations of analytical predictions with the test data. The model tested is a state-of-the-art Boeing Helicopters Model 360 rotor with second generation transonic airfoils and a tapered-tip planform. Time histories of blade pressures (leading edge and various chordwise positions), blade loads, and blade motions were recorded in conditions ranging from hover to high speed forward flight to provide a comprehensive data base against which analysis tools can be compared. This paper is concerned with the hover portion of the data. Correlations are shown between the data and several analyses including a two-dimensional airfoil analysis to predict chordwise pressure distributions, a lifting line and lifting surface method rotor analysis to predict blade loading, and a semi-empirical leading edge pressure method to predict blade loading. The large volume of high quality data taken at DNW will serve as a comprehensive data base against which analysis tools may be compared.

## A88-40718\*# Flow Research, Inc., Kent, Wash. OPTIMIZING ADVANCED PROPELLER DESIGNS BY SIMULTANEOUSLY UPDATING FLOW VARIABLES AND DESIGN PARAMETERS

MAGDI H. RIZK (Flow Research, Inc., Kent, WA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 160-167. refs (Contract NAS3-24855) (AIAA PAPER 88-2532)

A scheme is developed for solving constrained optimization problems in which the objective function and the constraint function are dependent on the solution of the nonlinear flow equations. The scheme updates the design parameter iterative solutions and the flow variable iterative solutions simultaneously. It is applied to an advanced propeller design problem with the Euler equations used as the flow governing equations. The scheme's accuracy, efficiency and sensitivity to the computational parameters are tested.

## A88-40728# NUMERICAL SIMULATION OF WINGS IN STEADY AND UNSTEADY GROUND EFFECTS

D. T. MOOK (Virginia Polytechnic Institute and State University, Blacksburg) and A. O. NUHAIT IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 246-257. refs (AIAA PAPER 88-2546)

A numerical simulation of steady and unsteady ground effect is developed. The simulation is based on the general unsteady vortex-lattice method, and is not restricted by planform, angle of attack, sink rate, dihedral angle, twist. etc. as long as stall does not occur. The present computed results are generally in close agreement with limited exact solutions and experimental data. The present results show the influences of various parameters on the aerodynamic coefficients for both steady and unsteady flows. Generally, the aerodynamic coefficients increase with proximity to the ground, the greater the sink rates the greater the increases. Increasing the aspect ratio increases both the steady and unsteady ground effects for both rectangular and delta planforms. The steady ground effect increases the rolling moment and the side force. The present results serve to demonstrate the potential of the Author present approach.

## A88-40729# TRANSONIC EULER CALCULATIONS OF A WING-BODY CONFIGURATION USING A HIGH-ACCURACY TVD SCHEME

CHUNG-JIN WOAN (Rockwell International Corp., Los Angeles, CA) and SUKUMAR R. CHAKRAVARTHY (Rockwell International Science Center, Thousand Oaks, CA) IN: AIAA Applied

Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 258-268, Research supported by the Rockwell International Independent Research and Development Program. refs (AIAA PAPER 88-2547)

A high-accuracy TVD Euler solver developed by the second author is used to calculate flowfields of an NACA research-type 45-degree swept wing-fuselage configuration at Mach numbers of 0.9 and 1.2 and an angle of attack of 6 degrees. A unique feature in the present calculation is that the flowfield is partitioned into a series of contiguous blocks, each being a nearly rectangular parallelopiped in shape. A grid of H-type is generated for each block independently of others. For efficiency of flow calculation, these blocked grids are combined into a smaller number of solution blocks. The combined grid has large grid-line slope discontinuities within the blocks and at block interfaces. Calculated results compared with experimental data indicate that the high-accuracy TVD Euler solver can calculate transonic flowfields efficiently and accurately on a such multi-block grid, hence, the flowfield blockings and griddings of realistic aerodynamic configurations can be greatly simplified.

#### A88-40730#

#### **GRID GENERATION AND FLOW ANALYSES FOR** WING/BODY/WINGLET CONFIGURATIONS

N. JONG YU, HAI-CHOW CHEN, ALLEN W. CHEN, and K. ROBYN WITTENBERG (Boeing Co., Seattle, WA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 269-275. Research supported by the Boeing Independent Research and Development Program. refs

(AIAA PAPER 88-2548)

A grid generation code together with both full potential and Euler flow analysis codes has been developed for the study of wing/body/winglet configurations. The grid generation code solves a set of elliptic equations to generate the field grids. Both the full potential and the Euler flow codes solve the basic conservation equations of fluid mechanics using a finite volume formulation. A highly efficient multigrid scheme is employed in both the full potential code and the Euler code to insure fast and reliable convergence of the iterative solution procedure. The advantages and the disadvantages of using the full potential code vesus the Euler code for wing/winglet analyses are discussed. Test/theory comparisons show that the Euler code gives better results, even at subcritical flow conditions.

#### A88-40731\*# Vigyan Research Associates, Inc., Hampton, Va. **EXPERIMENTAL INVESTIGATION OF NON-PLANAR SHEARED OUTBOARD WING PLANFORMS**

D. A. NAIK (Vigyan Research Associates, Inc., Hampton, VA) and C. OSTOWARI (Texas A & M University, College Station) AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 276-286. Research supported by Texas A&M University. refs (Contract NAG1-344)

(AIAA PAPER 88-2549)

The outboard planforms of wings have been found to be of prime importance in studies of induced drag reduction. This conclusion is based on an experimental and theoretical study of the aerodynamic characteristics of planar and nonplanar outboard wing forms. Six different configurations; baseline rectangular, planar sheared, sheared with dihedral, sheared with anhedral, rising arc, and drooping arc were investigated for two different spans. Span efficiencies as much as 20 percent greater than baseline can be realized with nonplanar wing forms. Optimization studies show that this advantage can be achieved along with a bending moment benefit. Parasite drag and lateral stability estimations were not included in the analysis.

#### **ARR-40732#**

#### WAKE RAKE STUDIES BEHIND A SWEPT SURFACE, CANARD AIRCRAFT

NEAL J. PFEIFFER (Beech Aircraft Corp., Wichita, KS) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 287-292. refs (AIAA PAPER 88-2552)

A wake rake with 21 five hole probes was flown on a Beech Starship prototype at various locations behind the aft wing, vertical stabilizer, and forward wing. Wind tunnel measurements were made with a single transversing five hole probe to match the flight conditions for the appropriate rake locations. Wake velocity profiles and momentum equation integrations for flight and wind tunnel are compared.

#### A88-40733#

#### **DETERMINATION OF THE AERODYNAMIC** CHARACTERISTICS OF THE MISSION ADAPTIVE WING

STEPHEN B. SMITH (USAF, Flight Test Center, Edwards AFB, CA) and DAVID W. NELSON (Boeing Co., Seattle, WA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 293-303. refs (AIAA PAPER 88-2556)

The Advanced Fighter Technology Integration AFTI/F-111 program is an on-going joint Air Force/NASA/Boeing research program designed to develop and demonstrate the potential technology enhancements of the Mission Adaptive Wing (MAW). The primary features of the MAW are smooth contour, variable camber leading and trailing edge surfaces which can modify wing contour in flight by means of an internal linkage system, and flexible skins. Extensive wind tunnel and flight test data were gathered during the course of the program to define the aerodynamic performance benefits attributed to the MAW. Full scale aerodynamic characteristics and predicted performance were initially based on a 1/12 scale model wind tunnel data base and a theoretical FLEXSTAB model used to adjust the data. Flight testing was conducted to determine lift, drag, buffet and wing upper and lower surface pressures. The flight test data served to verify the wind tunnel predictions and to provide a data base for follow-on analyses.

#### A88-40734\*# Stanford Univ., Calif.

#### NAVIER STOKES COMPUTATION OF THE FLOW FIELD OVER DELTA WINGS WITH SPANWISE LEADING EDGE BLOWING

DAVID T. YEH, DOMINGO A. TAVELLA, LEONARD ROBERTS (Stanford University, CA), and KOZO FUJII (National Aerospace Laboratory, Chofu, Japan) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 304-311. refs

(Contract NCC2-341)

(AIAA PAPER 88-2558)

The concept of spanwise leading edge blowing, a means of controlling the position and strength of leading edge vortices, is analyzed by numerical solutions of the three-dimensional Thin-Layer Navier Stokes equations. The leading edge jet is simulated by defining a permeable boundary, corresponding to the jet slot, where suitable boundary conditions are implemented. Numerical results agree favorably with experimental measurements. It is found that the use of spanwise leading edge blowing not only magnifies the size and strength of the leading edge vortices, but also moves the vortex cores outboard and upward. As a result, the increase in lift comes primarily from the greater nonlinear vortex lift. The presence of the leading edge jet stream displaces the flow outboard, thereby increasing the effective aspect ratio of the delta wing. However, blowing causes earlier vortex breakdown, thus decreasing the stall angle.

Author

#### A88-40735\*# Notre Dame Univ., Ind. LEADING EDGE VORTEX DYNAMICS ON A PITCHING DELTA WING

S. P. LEMAY, S. M. BATILL, and R. C. NELSON (Notre Dame, University, IN) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 312-320. Research supported by the University of Notre Dame.

(Contract NAG1-727) (AIAA PAPER 88-2559)

A study of the dynamic behavior of the leading edge vortices on a delta wing undergoing oscillatory pitching motion is presented. A sharp edge, flat plate, delta wing having a sweep angle of 70 deg was used in this investigation. The wing was sinusoidally pitched about its 1/2 chord position at reduced frequencies ranging from k = 2(pi)fc/u = 0.05 to 0.30 at chord Reynolds numbers between 90,000 and 350,000, for angle of attack ranges of 29 to 39 deg and 0 to 45 deg. During these dynamic motions, visualization of the leading edge vortices was obtained by marking the vortices with TiCl4 introduced through ports located near the model apex. The location of vortex breakdown was recorded using high speed motion picture photography. The motion picture records were analyzed to determine vortex trajectory and breakdown position as a function of angle of attack. When the wing was sinusoidally pitched, a hysteresis was observed in the location of breakdown position. This hysteresis increased with reduced frequency. The velocity of breakdown propagation along the wing, and the phase lag between model motion and breakdown location were also determined. Detailed information was also obtained on the oscillation of breakdown position in both static and dynamic Author

#### A88-40736#

## A METHOD TO INCREASE THE ACCURACY OF VORTICAL FLOW SIMULATIONS

KOZO FUJII (Tokyo, University, Kanagawa, Japan) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 321-328. refs (AIAA PAPER 88-2562)

Even with recent supercomputers having a large memory, Navier-Stokes simulations for vortical flows do not provide satisfactory results because of the lack of grid resolution to accurately simulate strength of separation vortices. To overcome this problem, a zonal method is newly developed to increase the number of the grid points locally. Interface scheme which is critical for an efficient zonal method is based on the Fortified Navier-Stokes approach. Application to both two-dimensional conical and three-dimensional delta wing problems indicates this simple zonal method can improve the accuracy of vortical flow simulations.

Author

#### A88-40737#

### EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE VORTEX FLOW OVER A YAWED DELTA WING

NICK G. VERHAAGEN and STEVE H. J. NAARDING (Delft, Technische Hogeschool, Netherlands) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 329-339. refs (AIAA PAPER 88-2563)

The influence of yaw on the flow about a sharp-edged biconvex delta wing of a unit aspect ratio is investigated using flow visualization techniques, as well as pressure and force balance measurements. The tests have been carried at a constant incidence of 21.1 deg and at angles of sideslip ranging from zero to 20 deg. The free stream velocity was 44 m/sec, corresponding to a Reynolds number of 2.5 million, based on root chord. Up to 12 deg sideslip, the asymmetry of the vortex crossflow and surface pressure distribution depends on the increasing asymmetry in the strength and position of the vortices, as well as on boundary layer transition. At larger angles of sideslip the vortex flow and pressure distribution is in addition influenced by asymmetric bursting. The flow about the yawed wing is computed using a

slender-body free-vortex-sheet method. Good agreement is obtained with experimental data on the part of the wing away from the apex and trailing edge.

Author

#### A88-40738#

## PNS CALCULATIONS OF HYPERSONIC TRANSITIONAL FLOW OVER CONES

T. BLUM and H. YOSHIHARA (Boeing Co., Seattle, WA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 340-346. refs (AIAA PAPER 88-2565)

The McDonald/Fish (1972) equation was incorporated into the Parabolic Navier-Stokes method. The resulting approach yielded computations of hypersonic transitional flows over cones that agreed well with experiment. Specifically, the flow over two cones of 10 and 6 deg (half-angle) were computed at freestream Mach numbers of 6 and 13.27 respectively. The Stanton number curve for the 10 deg cone matched well with experiment and earlier boundary layer computations. The transition and turbulent segments of the 10 deg case agreed well with experiment while a laminar mismatch was observed. For completeness, skin friction curves and the precursor and overshoot effects are given although corresponding experimental data are not available.

## A88-40739\*# Dynamic Engineering, Inc., Newport News, Va. COMPUTATIONAL VALIDATION OF A PARABOLIZED NAVIER-STOKES SOLVER ON A SHARP-NOSE CONE AT HYPERSONIC SPEEDS

LAWRENCE D. HUEBNER (Dynamic Engineering, Inc., Newport News, VA), JAMES L. PITTMAN (NASA, Langley Research Center, Hampton, VA), and ARTHUR D. DILLEY (Analytical Services and Materials, Inc., Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 347-356. refs (AIAA PAPER 88-2566)

Perfect gas computational results from a newly-developed upwind, parabolized Navier-Stokes (PNS) solver are compared with an existing set of experimental laminar results for a 10-deg half-angle circular cone at freestream Mach number of 7.95. Comparisons were performed with surface pressure and heat transfer data, as well as with flowfield pitot measurements. The PNS code predicted the surface quantities accurately up through 20-deg angle-of-attack, including crossflow separation, and correctly defined the location of the bow shock and the edge of the boundary layer. The importance of cell Reynolds number, grid density, and thermal boundary conditions to the accurate prediction of the flowfield are examined through numerical emamples.

Author

#### A88-40741#

## VISUALIZATION AND ANEMOMETRY ANALYSES OF FORCED UNSTEADY FLOWS ABOUT AN X-29 MODEL

J. ASHWORTH, T. MOUCH, and M. LUTTGES (U.S. Air Force Academy, Colorado Springs, CO) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 378-388. USAF-supported research. refs (AIAA PAPER 88-2570)

The applicability of forced unsteady flow-induced lift enhancement technology is demonstrated by an investigation comparing flow visualization and hot wire velocity measurements of the flow about an X-29 wind tunnel model. Intricate interactions are noted between wingtip and leading edge vortices on the surface of the canard; these structures convect downstream, and influence the flow patterns of the swept-forward wings. Several hypotheses formulated during visualization studies are supported by hot wire velocity measurements taken above and below the surface of the wing.

O.C.

#### A88-40742#

### EXPERIMENTAL AND NUMERICAL STUDY OF THE PROPELLER/FIXED WING INTERACTION

D. FAVIER, C. MARESCA, C. BARBI (Aix-Marseille II, Universite, Marseille, France), and G. FRATELLO IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 389-398. refs (Contract DRET-85-115)

(AIAA PAPER 88-2571)

Due to the recent development of high efficiency propeller airplanes, it has become necessary to better understand the effect of the slipstream on the nearby aircraft components. The slipstream influence has been investigated in a series of wind tunnel tests on propeller/nacelle/wing at subsonic speed. The experimental investigation was pursued so that the respective influence effect of each element has been deduced: propeller slipstream mean effects on the wing aerodynamic behavior as well as the modification induced by the wing on the propeller thrust and torque coefficients. The total aerodynamic loads as well as pressure distribution on the wing has been measured. A comparison is made with numerical pressure coefficient results obtained by modeling a wing immersed in the propeller slipstream calculated via a lifting line method.

#### A88-40743#

#### NUMERICAL ANALYSIS OF MULTIPLE ELEMENT HIGH LIFT DEVICES BY NAVIER STOKES EQUATION USING IMPLICIT TVD FINITE VOLUME METHOD

EIJI SHIMA (Kawasaki Heavy Industries, Ltd., Kakamigahara, Japan) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 399-406. refs

(AIAA PAPER 88-2574)

This paper deals with the analysis of multiple element high lift devices by solving the Navier-Stokes equations using the TVD (Total Variation Diminishing) finite difference method. In order to generate a computational grid around the multiple element airfoils automatically, the grid generator using the elliptic method, in which Poisson equations are by the finite difference method, combined with 2-D panel method is developed. As to the flow solver, some improvements are added to the TVD scheme to calculate low Mach number flows efficiently. Numerical calculations are carried out for the single slotted flap configuration.

#### A88-40744#

### NUMERICAL PREDICTION OF AERODYNAMIC PERFORMANCE FOR A LOW REYNOLDS NUMBER AIRFOIL

FEI-BIN HSIAO (National Cheng Kung University, Tainan, Republic of China) and CHENG-CHIANG HSU IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 407-413. refs (AIAA PAPER 88-2575)

A simple scheme is developed for predicting the aerodynamic parameters and the bubble formation of a NACA 63(3)-018 symmetric airfoil at Reynolds number 300,000, based on the chord. The modified potential flow solutions associated with the vortex wake model are obtained numerically to study the wake effect on the airfoil performance when the flow is separated on the surface. A reasonable agreement is made between the prediction and the experiment in the computed range of angles of attack. The CPU time for this scheme is very little when compared to some computational solvers.

## A88-40745\*# Ohio State Univ., Columbus. EXPERIMENTAL MEASUREMENTS ON AN OSCILLATING 70-DEGREE DELTA WING IN SUBSONIC FLOW

M. R. SOLTANI, M. B. BRAGG (Ohio State University, Columbus), and J. M. BRANDON (NASA, Langley Research Center, Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington,

DC, American Institute of Aeronautics and Astronautics, 1988, p. 414-427. refs

(AIAA PAPER 88-2576)

A series of low-speed wind tunnel tests on a 70-degree sharp leading-edged delta wing at both static and dynamic conditions were performed to investigate the aerodynamic forces and moments. Forces and moments were obtained from a six component internal strain gauge balance. Static results compared well with the previous experimental findings. Large amplitude dynamic motion was produced by sinusoidally oscillating the model over a range of reduced frequencies. Substantial force and moment overshoots, a delay in dynamic stall, and hysteresis loops between the values of aerodynamic loads in upstroke and downstroke motion were observed, all of which were strong functions of the reduced frequency. The aerodynamic forces and moments were influenced by the Reynolds number. Asymmetrical vortex bursting produced by nonzero sideslip angle created a complex rolling moment variations with angle of attack.

#### A88-40746#

## PITCH RATE AND REYNOLDS NUMBER EFFECTS ON A PITCHING RECTANGULAR WING

MICHAEL C. ROBINSON (USAF, Frank J. Seiler Research Laboratory, Colorado Springs, CO) and JOHN B. WISSLER (U.S. Air Force Academy, Colorado Springs, CO) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 428-440. USAF-sponsored research.

(AIAA PAPER 88-2577)

Unsteady pressure measurements were collected from a pitching NACA 0015 wing at several span locations. The transient pressure signatures indicated the formation of both a leading edge and wingtip vortex as the wing pitched from 0 to 60 deg. Inboard, away from the wingtip, the dynamic stall vortex initiation and convection appeared two-dimensional. Near the wingtip, strong orthogonal vortex-vortex interactions prolonged vortex residence times and enhanced the sectional lift coefficients. These transient enhancements were directly dependent upon pitch rate. Reynolds number effects on vortex development were minor over the limited range tested.

## A88-40747\*# Mississippi State Univ., Mississippi State. THREE-DIMENSIONAL UNSTEADY TRANSONIC VISCOUS-INVISCID INTERACTION USING THE EULER AND BOUNDARY-LAYER EQUATIONS

DAVID L. WHITFIELD (Mississippi State University, Mississippi State) and SHAHYAR PIRZADEH IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 441-453. refs (Contract NAG1-226)

(AIAA PAPER 88-2578)

The objective of this study is the development of a numerical technique which can provide three-dimensional, time-accurate, compressible, turbulent flow solutions in a practical and relatively economical way. The approach taken is that of the method of viscous-inviscid interaction. The Euler equations are assumed to govern the outer inviscid portion of the flow, and the viscous layer close to the solid wall is described by a set of integral boundary-layer equations. The viscous solutions are obtained in a direct fashion with a weighted-average phase error scheme. The method of equivalent sources is used for viscous-inviscid coupling. Steady-state and unsteady computations for an AGARD airfoil and a wing show that satisfactory engineering solutions can be obtained for attached, high Reynolds number flows using this method. Quasi-unsteady interactions are shown to produce similar results to those provided by true-unsteady interactions. Considerable computer resources can be saved for some cases by using quasi-unsteady interactions. Author

#### A88-40748# UNSTEADY AERODYNAMIC FORCES AT LOW AIRFOIL PITCHING RATES

JULIE A. ALBERTSON, TIMOTHY R. TROUTT (Washington State University, Pullman), and CHRISTOPHER R. KEDZIE (USAF, Frank J. Seiler Research Laboratory, Colorado Springs, CO) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 454-462. refs (Contract F49620-85-C-0013) (AIAA PAPER 88-2579)

Experiments were conducted on a NACA-0015 airfoil undergoing low constant pitch rates to study the effects of dynamic stall formation on the airfoil upper surface pressure field. The airfoil was pitched about pivot locations of 0.25c, 0.50c, and 0.75c at nondimensional pitch rates below 0.2. Lift and drag coefficients were evaluated for all cases, and smoke flow visualization at low pitch rates was studied for the quarter chord pivot location. Results indicate that the greatest increases in lift due to the pitching motion occur prior to the nondimensional pitch rate of 0.1 for all three pivot locations. The effects of pitch rate on the maximum lift and drag values appear similar for the three pivot locations studied. Lift to drag ratios show significant enhancement even at very low nondimensional pitch rates. Flow visualization indicates that the leading-edge dynamic stall vortex is present even at very low nondimensional pitch rates.

A88-40749# IMPINGEMENT OF ORTHOGONAL UNSTEADY VORTEX STRUCTURES ON TRAILING AERODYNAMIC SURFACES

JOHN M. WALKER and MICHAEL C. ROBINSON (USAF, Frank J. Seiler Research Laboratory, Colorado Springs, CO) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 463-472. USAF-supported research. refs

(AIAA PAPER 88-2580)

Wind tunnel experiments were conducted with a generic wing-canard type configuration which consisted of two 6-in. NACA 0015 sections placed in tandem one chord length apart. The 1.8c semispan canard was pitched from 0 to 60 deg angle-of-attack at constant nondimensional rates ranging from 0.05 to 0.2 about its quarter-chord axis. These motions produced three-dimensional dynamic stall and wing tip vortex flows which impinged on the 2.5c semispan trailing wing set at a geometric angle of incidence of zero deg. Smoke-wire flow visualization and dynamic surface pressure measurements were performed to study the effects of the unsteady vortical wakes on the trailing wing. These unsteady vortex structures produced by the pitching canard elicited complex, time dependent secondary flows about the trailing wing which in turn produced large dynamic loads.

A88-40750#

#### UNSTEADY FLOW INTERACTIONS BETWEEN THE WAKE OF AN OSCILLATING AIRFOIL AND A STATIONARY TRAILING **AIRFOIL**

STEPHEN A. HUYER and MARVIN W. LUTTGES (Colorado, University, Boulder) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Washington, DC, American Instit Astronautics, 1988, p. 473-482. refs

(Contract F49620-83-K-0009)

(AIAA PAPER 88-2581)

The flow field interaction between the unsteady wake generated by an oscillating upstream airfoil and stationary trailing airfoil was examined in detail for high trailing airfoil angles of attack. Mean angle and oscillation amplitude of the upstream airfoil were held constant across sinusoidally pitching at two reduced frequencies. The angle of attack of the trailing airfoil was then varied to angles exceeding stall in order to evaluate the possibility of dynamically re-attaching flow. Flow interactions were recorded and measured multiple exposure, phase locked flow visualization photographs and surface pressure measurements. The upstream airfoil produced a dynamic stall-trailing edge tandem vortex pair followed by a separated wake region. These unsteady flow fields then interacted with the trailing airfoil producing highly transient aerodynamic loading evidenced by the measured pressure distribution. Both lift enhancement and thrusting effects were produced on the trailing airfoil under certain test conditions. Since the flow fields produced significant complexities in terms of control, additional studies need to be conducted to identify possible methods of enhancing positive and avoiding adverse flow interactions occurring between active and passive tandem lifting

#### A88-40751#

#### A COMPARATIVE STUDY OF DIFFERING VORTEX STRUCTURES ARISING IN UNSTEADY SEPARATED FLOWS STEPHEN A. HUYER, MARK A. REAVIS, and MARVIN W. LUTTGES (Colorado, University, Boulder) IN: AIAA Applied

Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 483-491. refs (Contract F49620-85-C-0013)

(AIAA PAPER 88-2582)

The vortex structures arising in two different unsteady separated flow tests were examined in detail. Flow fields resulting from the deployment of a periodically deforming leading edge (PDLE) and an oscillating flat plate were studied and compared. The PDLE produced two separate vortex structures during each complete deformation cycle. It was found through flow visualization and hot-wire anemometry that these two structures exhibited quite different characteristics. The primary vortex, initiated at approximately maximum PDLE deployment, was characterized by low, constant velocities within the vortex. The measured velocities increased threefold, to 120 percent freestream values, across a hot-wire displacement of 3 mm. The second vortex, initiated at approximately minimum PDLE deployment, exhibited a more evenly graded vortex rotation rate with no evidence of spatially-dependent stepwise changes in velocity. The vortex structures produced by an oscillating flat plate were also examined. It was found that a reduced frequency of 3 yielded a more cohesive vortex compared to that produced by a reduced frequency of 1. The structures produced by PDLE deployment were also considerably weaker than those produced by an oscillating flat plate. Author

#### A88-40752\*# Sterling Software, Palo Alto, Calif. AN UPWIND DIFFERENCING SCHEME FOR THE TIME-ACCURATE INCOMPRESSIBLE NAVIER-STOKES **EQUATIONS**

STUART E. ROGERS (Sterling Software, Palo Alto, CA) and DOCHAN KWAK (NASA, Ames Research Center, Moffett Field, IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 492-502. refs

(AIAA PAPER 88-2583)

The two-dimensional incompressible Navier-Stokes equations are solved in a time-accurate manner in using the method of pseudocompressibility. Using this method, subiterations in pseudotime are required to satisfy the continuity equation at each time step. An upwind differencing scheme based on flux-difference splitting is used to compute the convective terms. The upwind differencing is biased based on the sign of the local eigenvalue of the Jacobian matrix. Third-order or fifth-order spatial accuracy is maintained throughout the interior grid points. The equations are solved using an implicit line-relaxation scheme. This solution scheme is stable and is capable of running at large time steps in pseudotime, leading to fast convergence for each physical time step. A variety of computed results are presented to validate the present scheme. Results for the flow over an oscillating plate are compared with the exact analytic solution, good agreement is seen. Excellent comparison is obtained between the computed solution and the analytical results for inviscid channel flow with an oscillating back pressure. Flow solutions over a circular cylinder with vortex

shedding are also presented. Finally, the flow past an airfoil at -90 deg angle-of-attack is also computed.

### APPLICATION OF NAVIER-STOKES ANALYSIS TO PREDICT THE INTERNAL PERFORMANCE OF THRUST VECTORING TWO-DIMENSIONAL CONVERGENT-DIVERGENT NOZZLES

G. J. SOVA (Rockwell International Corp., Los Angeles, CA) IN: AlAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 522-527. Research supported by the Rockwell International Independent Research and Development Program. refs (AIAA PAPER 88-2586)

Rockwell's two-dimensional Navier-Stokes solver has been used to predict the internal performance of a thrust vectoring two-dimensional nozzle operating at pressure ratios of 5.04 (unseparated) and 3.03 (separated). Turbulent flow is assumed and the Baldwin-Lomax eddy viscosity formulation is used in the Reynolds-averaged form of the Navier-Stokes equations. Comparisons with test data are quite favorable. It is anticipated that routine analysis of generic nozzles can be realized in a timely (less than one man week of effort) and cost effective manner.

#### A88-40756\*# PEDA Corp., Palo Alto, Calif. CSCM NAVIER-STOKES THERMAL/AERODYNAMIC ANALYSIS OF HYPERSONIC NOZZLE FLOWS WITH SLOT INJECTION AND WALL COOLING

WILLIAM H. CODDING, C. K. LOMBARD, and J. Y. YANG (PEDA Corp., Palo Alto, CA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 528-542. refs (Contract NAS2-12243; NASA ORDER A-56829-C)

(AIAA PAPER 88-2587)

The Conservative Supra-Characteristic Method (CSCM) Navier-Stokes solver is applied to ascertain the problems inherent in the design of a nominal Mach 14 nozzle for NASA-Ames' 3.5-ft Hypersonic Wind Tunnel; attention is given to the effects of boundary layer cooling systems on the aerodynamic redesign of the nozzle throat region. Complete nozzle flowfields are calculated with and without slot injection of either hot or cold fluid into the boundary layer just upstream of the throat, as well as with alternatively adiabatic and cold walls. The CSCM method is capable of resolving subtle differences in the flows.

#### A88-40757\*# North Carolina State Univ., Raleigh. UNSTEADY VISCOUS-INVISCID INTERACTION PROCEDURES FOR TRANSONIC AIRFOILS USING CARTESIAN GRIDS

CHARLES C. FENNO, JR., H. A. HASSAN (North Carolina State University, Raleigh), and PERRY A. NEWMAN (NASA, Langley Research Center, Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 543-551. refs (Contract NGT-34-002-801; NAGW-1072)

(AIAA PAPER 88-2591)

A viscous-inviscid interaction procedure for transonic airfoils using an Euler/integral boundary layer formulation and Cartesian grids is presented. The approach is based on a time dependent formulation for both the integral boundary layer equations and the Euler equations. Effects of upstream history on the shear stress are modeled by a time dependent rate equation derived from the turbulent kinetic energy equation. Results are presented for two of the test cases reported by Cook et al. (1979) for the RAE 2822 supercritical airfoil and one of the cases reported by Harris (1981) for the NACA 0012 symmetric airfoil. In general, the results are in good agreement with experiment.

#### A88-40758#

TURBULENT EDDY VISCOSITY MODELING IN TRANSONIC SHOCK/BOUNDARY LAYER INTERACTIONS

G. R. INGER (lowa State University of Science and Technology, Ames) IN: AIAA Applied Aerodynamics Conference, 6th. Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 552-560. refs

(AIAA PAPER 88-2592)

The treatment of turbulence effects on transonic shock/turbulent boundary layer interaction is addressed within the context of a triple deck approach valid for arbitrary practical Reynolds numbers between 1000 and 10 billion. The modeling of the eddy viscosity and basic turbulent boundary profile effects in each deck is examined in detail using Law-of-the-Wall/Law-of-the-Wake concepts as the foundation. Results of parametric studies showing how each of these turbulence model aspects influences typical interaction zone property distributions (wall pressure, displacement thickness and local skin friction) are presented and dis-Author

#### A88-40760#

#### NONINTRUSIVE MEASUREMENTS OF VORTEX FLOWS ON DELTA WINGS IN A WATER TUNNEL

STEVEN L. MORRIS, DONALD T. WARD (Texas A & M University, College Station), GERALD N. MALCOLM, and LIANE C. LEWIS (Eidetics International, Torrance, CA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 568-581. refs (Contract F49620-87-C-0069) (AIAA PAPER 88-2595)

The 'ExpertVision' nonintrusive videoimaging system has been used as the basis of a novel method for quantifying vortex flow field data in a water tunnel, so that the location and movement of the vortex core can be ascertained through the systematic tracking of colored dye jets ejected from models into the surrounding flow field. Automated data-reduction software then calculated position. velocity, and acceleration from the trace of specified images in the digitized video field-of-view. Vortex core burst point dynamics were also quantified. Forced oscillation measurements furnished phase correlations between model motion and vortex core velocities, as well as between model motion and vortex-burst point location.

#### A88-40761#

### THE EFFECT OF CROSS FLOW ANGLE ON THE DRAG AND LIFT COEFFICIENTS OF NON-CIRCULAR CYLINDER WITH

BANDU N. PAMADI (Vigyan Research Associates, Inc., Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 582-592. refs (AIAA PAPER 88-2599)

In a recent study, the installation of a pair of thin strakes on the windward face of a noncircular cylinder in subcritical flow was found to give substantial drag reduction. The primary fluid flow mechanism which gave optimum drag reduction up to 81.5 percent was identified as the smooth, tangential, turbulent reattachment of the flow separating from the strakes at the corners. In this paper, the effect of cross flow incidence on this flow mechanism is investigated. Also, the drag and lift forces of the body are presented for cross flow angles up to + or - 90 deg.

#### A88-40762\*# Old Dominion Univ., Norfolk, Va. **CALCULATIONS OF THREE-DIMENSIONAL FLOWS USING** THE ISENTHALPIC EULER EQUATIONS WITH IMPLICIT **FLUX-VECTOR SPLITTING**

FRANK E. CANNIZZARO, E. VON LAVANTE (Old Dominion University, Norfolk, VA), and N. DUANE MELSON (NASA, Langley Research Center, Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 593-614. refs

(Contract NAG1-633) (AIAA PAPER 88-2516)

A numerical method for solving the isenthalpic form of the Euler equations is developed. The method is based on the concept of flux vector splitting in its implicit form applied to a cell centered finite volume scheme. Approximate factorization is implemented in solving the implicit part of the governing equations. Time marching to a steady state solution requires short computational times due to the relative efficiency of the basic method. Computational times are further reduced by the implementation of multigrid. Results for several basic cases are shown.

A88-40763\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

## FLIGHT TESTS OF EXTERNAL MODIFICATIONS USED TO REDUCE BLUNT BASE DRAG

SHERYLL GOECKE POWERS (NASA, Flight Research Center, Edwards, CA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 615-628. Previously announced in STAR as N88-20279. refs (AIAA PAPER 88-2553)

The effectiveness of a trailing disk (the trapped vortex concept) in reducing the blunt base drag of an 8-in diameter body of revolution was studied from measurements made both in flight and in full-scale wind-tunnel tests. The experiment demonstrated the significant base drag reduction capability of the trailing disk to Mach 0.93. The maximum base drag reduction obtained from a cavity tested on the flight body of revolution was not significant. The effectiveness of a splitter plate and a vented-wall cavity in reducing the base drag of a quasi-two-dimensional fuselage closure was studied from base pressure measurements made in flight. The fuselage closure was between the two engines of the F-111 airplane; therefore, the base pressures were in the presence of jet engine exhaust. For Mach numbers from 1.10 to 1.51, significant base drag reduction was provided by the vented-wall cavity configuration. The splitter plate was not considered effective in **Author** reducing base drag at any Mach number tested.

A88-40764\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

RIBLET DRAG REDUCTION AT FLIGHT CONDITIONS

MICHAEL J. WALSH, WILLIAM L. SELLERS, III, and CATHERINE B. MCGINLEY (NASA, Langley Research Center, Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 629-638. refs (AIAA PAPER 88-2554)

Paper describes perforated and nonperforated riblet tests on the fuselage of a modified Learjet Model 28/29 twin-engine business jet at Reynolds numbers 1.0-2.75 x 10 to the 6th/ft and Mach numbers 0.3-0.7. Drag reductions of the order of 6 percent at nondimensional wall spacings of 12 were obtained using boundary-layer rakes and direct drag balances. At the measurement locations the Reynolds number based on distance was 1.0-46 x 10 to the 6th. The nondimensional wall spacing for maximum drag reduction was well-predicted by low-speed wind-tunnel data, but the maximum drag reduction was lower. The low drag is tentatively ascribed to various instrumentation difficulties and the flow field on the aircraft. Riblets with 0.010-in. perforations at center spacings of 0.25 in. were found to give the same drag reduction as nonperforated riblets.

A88-40765\*# Analytical Services and Materials, Inc., Hampton,

#### DESIGN OF LOW REYNOLDS NUMBER AIRFOILS. I

W. PFENNINGER and C. S. VEMURU (Analytical Services and Materials, Inc., Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 639-655. refs (Contract NAS1-18235)

(Contract NAS1-18235) (AIAA PAPER 88-2572) The low Reynolds number airfoils designated ASM-LRN-003 and -007 have been designed for high section L/D ratios using Drela's (1985) design-and-analysis code; close to 70-percent laminar flow is maintained on the upper surfaces, and 100-percent on the lower, at coefficients of lift of 1.0-1.3, assuming optimum laminar separation and transition control on the upper surface by means of suitable turbulators. If peak performance is critical, airfoils of this type with an undercut front lower surface and a correspondingly sharper leading edge may be resorted to. O.C.

A88-40766\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

## EXPERIMENTAL AND THEORETICAL STUDY OF THE EFFECTS OF WING GEOMETRY ON A SUPERSONIC MULTIBODY CONFIGURATION

STEVEN X. S. BAUER and S. NAOMI MCMILLIN (NASA, Langley Research Center, Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 656-664. refs (AIAA PAPER 88-2510)

An experimental and theoretical investigation of planform effects on a low-fineness ratio multibody configuration was conducted in NASA-Langley Research Center's Unitary Plan Wind Tunnel at Mach number of 1.6, 1.8, 2.0 and 2.16. Experimental and theoretical values of lift, drag, and pitching moment as well as surface pressures were obtained on several configurations which varied in both outboard-wing panel and inboard-wing panel planforms. The three outboard-wing panels were a 65 -deg delta and two trapezoidal wing planforms. An unswept and a 60-deg swept inboard-wing panels were also tested. The purpose of the study was to determine the effect of wing planform on the supersonic aerodynamics. The large trapezoidal wing provided increased performance over the small trapezoidal wing primarily due to a reduction in the zero-lift drag coefficient. The swept inboard-wing panel planforms provided a slightly higher L/D than the unswept inboard-wing panel due to a minimal improvement in zero-lift drag. Linear-theory aerodynamic codes were used to analyze the effect of planform on the supersonic aerodynamics and were found to generally produce adequate results.

## A88-40767\*# Vigyan Research Associates, Inc., Hampton, Va. NAVIER-STOKES COMPUTATION OF FLOW AROUND A ROUND-EDGED DOUBLE-DELTA WING

C.-H. HSU (Vigyan Research Associates, Inc., Hampton, VA) and C. H. LIU (NASA, Langley Research Center, Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 665-673. refs (AIAA PAPER 88-2560)

Computations of three-dimensional vortical flows over a thin round-edged double-delta wing with an aspect ratio of 2.05 are performed using an implicit upwind-relaxation finite-difference scheme. The effects of grid and angle of attack on the Navier-Stokes computations are studied. Coarse-grid calculations can not predict the detailed structures of the vortical flowfields for lack of grid resolution. On the contrary, fine-grid computations show that key features of vortex formation, interaction, and breakdown are simulated. Furthermore, computed lift coefficients and spanswise surface static pressure distributions are in good agreement with the experimental data up to alpha = 25 deg.

Author

## A88-40768# FURTHER ANALYSIS OF WING ROCK GENERATED BY FOREBODY VORTICES

L. E. ERICSSON (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 674-686. refs (AIAA PAPER 88-2597)

More intensive analytical efforts for the wing rock that can be

generated by forebody vortices have uncovered numerous flow phenomena capable of giving rise to the wing rock observed experimentally; comparatively small aircraft geometry changes result in the rise to dominant status of very different flow mechanisms, thereby affecting the nature of wing rock. Wing rock generated by slender forebody vortices is not only far more severe than slender wing rock due to asymmetric leading edge vortices, but is also that which is most prevalent in current and projected advanced aircraft types.

#### A88-40771#

## COMPUTATIONAL SIMULATION OF VORTEX GENERATOR EFFECTS ON TRANSONIC SHOCK/BOUNDARY LAYER INTERACTION

G. R. INGER (lowa State University of Science and Technology, Ames) and TIMOTHY SIEBERSMA AIAA, Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988. 8 p. refs (AIAA PAPER 88-2590)

The influence of shock/boundary layer interaction on a supercritical wing can extend significantly downstream within the boundary layer, and thus adversely affect global aerodynamic properties. This negative influence may be reduced with the appropriate application of boundary layer control. One method of boundary layer control, the vortex generator, has been shown to be effective in delaying separation by promoting mixing between the free stream and the boundary layer. In this study, we seek to simulate the effects of a vortex generator located ahead of the shock/boundary layer interaction zone on a supercritical wing. The vortex generator is represented by parameters characterizing the Law of the Wall/Law of the Wake structure of the turbulent boundary layer. This vortex generator model is integrated into a previously-developed computational model of a shock/boundary layer interaction that utilizes an appropriate triple deck theory of the interaction. The results of a parametric study of this simulated vortex generator effect on the interaction zone flow are then presented. Author

#### A88-40970

## UNSTEADY NONSIMILAR LAMINAR COMPRESSIBLE BOUNDARY-LAYER FLOW OVER A YAWED INFINITE CIRCULAR CYLINDER

R. VASANTHA and G. NATH (Indian Institute of Science, Bangalore, India) Archiwum Mechaniki Stosowanej (ISSN 0373-2029), vol. 39, no. 1-2, 1987, p. 13-26. refs

Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder has been studied when the external flow is nonhomentropic and varies arbitrarily with time. The governing partial differential equations have been solved numerically using an implicit finite-difference scheme with quasi-linearization technique. The results have been obtained for both an accelerating stream and fluctuating stream. The skin-friction and heat-transfer parameters respond significantly to the unsteadiness in the external flow field. It is observed that, in the case of nonhomentropic flow, the heat-transfer parameter increases along the streamwise coordinate up to some x and then decreases. The effects of the yaw angle and Mach number are found to be more pronounced for the unsteady case than for the steady case. Increase in wall temperature, Mach number and time cause the point of zero skin friction to shift upstream.

#### A88-40972

## DEVELOPMENT OF AN AIRFOIL OF HIGH LIFT/DRAG RATIO AND LOW MOMENT COEFFICIENT FOR SUBSONIC FLOW

W. KANIA and M. ANTOSIEWICZ (Instytut Lotnictwa, Warsaw, Poland) Archiwum Mechaniki Stosowanej (ISSN 0373-2029), vol. 39, no. 1-2, 1987, p. 63-72. refs

A NUMERICAL method is used to design a new airfoil of high lift/drag ratio and moment coefficient close to zero at the specified subsonic flow condition. Attainment of the desired aerodynamic properties of this airfoil is verified by performing special experimental studies in the trisonic wind tunnel. The aerodynamic characteristics of the designed airfoil are compared with several advanced and conventional airfoils.

#### A88-41048#

#### ON INVERSE AIRFOIL DESIGN

PRABIR DARIPA (Texas A & M University, College Station) AIAA, Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988. 10 p. refs (AIAA PAPER 88-2573)

We discuss mostly the theoretical aspects of our approach to inverse airfoil design. The methods we propose to solve the inverse airfoil problem for subcritical and supercritical flows are based on the formulation of the problem in the potential plane. Some of our methods have been used to generate subcritical airfoils. Further numerical work for subsonic and transonic cases is in progress.

Author

#### A88-41092#

### A NUMERICAL STUDY OF VISCOUS FLOW IN INLETS AND AUGMENTORS

J. E. DEESE and R. K. AGARWAL (McDonnell Douglas Research Laboratories, Saint Louis, MO) AIAA, Aerospace Sciences Meeting, 26th, Reno, NV, Jan. 11-14, 1988. 8 p. refs (AIAA PAPER 88-0187)

Flowfields through two-dimensional and axisymmetric inlets and thrust-augmenting ejectors are modeled by use of the thin-layer approximation to the unsteady Reynolds-averaged Navier-Stokes equations. The equations are solved by an explicit multistage Runge-Kutta time-stepping method employing a finite-volume formulation on body-conforming curvilinear grids. Eddy viscosity models are used to describe turbulence effects. Results compare well with experimental data for transonic inlet flows. Improvements in turbulence modeling are needed for better prediction of ejector flowfields.

#### A88-41269

## ON THE USE OF SUBCYCLING FOR SOLVING THE COMPRESSIBLE NAVIER-STOKES EQUATIONS BY OPERATOR-SPLITTING AND FINITE ELEMENT METHODS

M. O. BRISTEAU, R. GLOWINSKI (Institut National de Recherche en Informatique et en Automatique, Le Chesnay, France), B. MANTEL, J. PERIAUX (Avions Marcel Dassault Breguet Aviation, Saint-Cloud, France), and G. S. SINGH (Bhabha Atomic Research Centre, Bombay, India) Communications in Applied Numerical Methods (ISSN 0748-8025), vol. 4, May-June 1988, p. 309-317. refs

(Contract DRET-83-403)

In this paper, the solution of the compressible Navier-Stokes equations by numerical techniques combining finite element approximations, operator splitting for the time discretization, and numerical treatment of the nonlinearities by subcycling, is discussed. In this context this means that on the basic time discretization interval a time integration is performed by a standard numerical scheme for initial-value problems (explicit schemes in this paper). Numerical results for flows around a NACA 0012 aerofoil are presented.

A88-41270\* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

## AN OVERVIEW OF HYPERSONIC AEROTHERMODYNAMICS GARY T. CHAPMAN (NASA, Ames Research Center, Moffett Field, CA) Communications in Applied Numerical Methods (ISSN 0748-8025), vol. 4, May-June 1988, p. 319-325. refs

This paper briefly reviews some national studies and new programs concerning hypersonic flight. The flight environment that will be encountered by this new class of hypersonic vehicles is described, and the fluid-dynamic and chemical phenomena that occur in hypersonic flight are examined. Ground-based facilities are briefly described, and their use in helping to validate the codes is examined.

C.D.

N88-22004# Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

## CONTROL OF LAMINAR FLOW AROUND OF THE WING IN FREE-AIR CONDITIONS

V. B. ZOZULYA and O. R. CHERANOVSKIY 4 Dec. 1987 16

Transl. into ENGLISH from Collection of Hydromechanics (USSR), issue 20, 1972 p 37 (AD-A187479; FTD-ID(RS)T-1042-87) Avail: NTIS HC A03/MF A01 CSCL 01A

The effect of the initial turbulence of flow on the distribution of the speed of suction from the boundary layer of the penetrated plate with the ideally smooth surface is examined. However, it is known that the initial turbulence of the atmosphere is considerably less than the corrected values. As the investigations, carried out by Shaubauer and Skramstad showed, with the sufficienty low turbulence level (order 0.08 percent) there is so-called upper critical Reynolds number. Therefore, the experimental confirmation of this face under the conditions of free atmosphere is of interest, and also the explanation of the minimally necessary suction intensity under such conditions. The decrease of initial turbulence in comparison with the value of turbulence in the duct by an order must lead to the noticeable increase in the extent of laminar section, which, however, under the conditions of the atmosphere must be limited by the value of the upper critical Reynolds number. In connection with this the value of suction intensity, necessary for the laminar flow, can be lowered approximately doubly in comparison with the values of intensity, obtained in the duct when epsilon = 0.2 percent.

N88-22005# Naval Postgraduate School, Monterey, Calif. HIGH REYNOLDS NUMBER, LOW MACH NUMBER, STEADY FLOW FIELD CALCULATIONS OVER A NACA 0012 AIRFOIL USING NAVIER-STOKES AND INTERACTIVE BOUNDARY LISA J. COWLES Dec. 1987

118 p

(AD-A189871) Avail: NTIS HC A06/MF A01 CSCL 20D

A Navier-Stokes code, developed by N. L. Sankar, and an Interactive Boundary Layer code, developed by Tuncer Cebeci, are implemented for high Reynolds number, low Mach flows over a NACA 0012 airfoil. Upper surface pressure distribution, coefficients of lift, coefficients of friction, and velocity profiles obtained from the Navier-Stokes code are compared to results obtained from the Cebeci Interactive Boundary Layer code for steady flow. The steady state cases investigated are at .3 Mach and Reynolds numbers of 1 to 5 million and at .12 Mach and a Reynolds number of 1.5 million.

N88-22006# Flow Research, Inc., Kent, Wash.
UNSTEADY AERODYNAMICS OF A WORTMANN FX-63-137 WING IN A FLUCTUATING WIND FIELD Final Report, 15 Sep. 1983 - 15 Sep. 1987

H.-T. LIU Nov. 1987 61 p (Contract N00014-83-C-0694)

(AD-A190128; FLOW-RR-431) Avail: NTIS HC A04/MF A01 CSCL 01A

An environmental aerodynamic test (EATS) was designed and assembled to investigate the effects of gust and turbulence on the performance of a full-scale Wortmann FX-63-137 wing. Experiments were conducted in the atmospheric boundary layer by directing the elevated wing into the prevailing wind for a range of Reynolds numbers from 80,000 to 450,000. The unsteady wind field, in essence, introduces significant and favorable effects on the aerodynamics in terms of lift overshoot, stall delay, reduction of drag at small angles of attack, and endurance enhancement. Further analysis of the field data was conducted to investigate the unsteady aerodynamic phenomena, such as the hysteresis loops and the spectra of the aerodynamic forces and the relation to the ambient wind conditions.

N88-22007# Arizona Univ., Tucson.

EXPERIMENTAL INVESTIGATION OF A SPANWISE FORCED MIXING LAYER Annual Report, 1 Jul. 1986 - 30 Jun. 1987

A. GLEZER, I. J. WYGNANSKI, and T. F. BALSA 7 Nov. 1987

(Contract AF-AFOSR-0324-86)

(AD-A190136; AFOSR-87-1903TR) Avail: NTIS HC A03/MF A01

The occurrence of three-dimensional motion within a plane

mixing layer results in a significant increase of the internal mixedness (mixing transition). The three-dimensional motion necessary for mixing is induced by streamwise, counter-rotating vortex pairs superimposed on the primary spanwise vortices. While their appearance in the plane mixing layer has been established, their origin and their evolution with increasing streamwise distance remains an enigma. Stability considerations indicate that an instability in the spanwise direction may lead to the generation of streamwise vorticity. This suggests that the flow may be susceptible to low level spanwise periodic forcing. Previous experiments have demonstrated that forcing allows the enhancement of individual instability modes and is an essential step towards understanding the evolution of the natural flow. Furthermore, application of forcing to the flow provides a powerful tool of considerable practical significance for the control of the downstream evolution. We have begun an experimental investigation of a plane mixing layer which is forced independently in the spanwise and streamwise directions. Our objective is to study the evolution of spanwise instability.

N88-22008# Douglas Aircraft Co., Inc., Long Beach, Calif. OSCILLATING AIRFOILS: ACHIEVEMENTS AND CONJECTURES Final Report, Oct. 1986 - Sep. 1987 31 p

TUNCER CEBECI Sep. 1987 (Contract F49620-87-C-0004)

(AD-A190490; MDC-K0535; AFOSR-87-1779TR) Avail: NTIS HC

A03/MF A01 CSCL 20D

Recent developments and applications of an interactive boundary layer procedure for unsteady flows are reviewed. The emphasis is on a model problem corresponding to an oscillating thin airfoil in laminar flows and results are reported for different amplitudes and frequencies of oscillation. The use of the characteristic box scheme, with its stability criterion, are shown to allow the accurate calculation of reverse flows and the interaction procedure removes the singularity to allow calculation through regions of separated flow. Although the current focus of the interactive boundary layer procedure has been on the leading edge region, it has general applicability and, together with models for transition and turbulent flows, it can provide the basis for a method to deal with oscillation airfoils and wings and the rapid movement of fixed wing arrangements at angles of attack up to and beyond those of dynamic stall. Calculations at high angles of attack show that the behavior of the unsteady separated leading edge flow has similarities to steady flows down-stream of surface corrugations. The use of linear stability theory in the latter case shows that the locations of the onset of transition moves upstream with severity of corrugation and can move inside the separation bubble. In practice this means that the bubbles will be shortened and analogy with unsteady flows suggests that transition may play GRA an important role.

N88-22009\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

COMPUTATIONAL FLUID DYNAMICS DRAG PREDICTION: RESULTS FROM THE VISCOUS TRANSONIC AIRFOIL **WORKSHOP** 

TERRY L. HOLST Apr. 1988 15 p Workshop held Jan. 1987 (NASA-TM-100095; A-88142; NAS 1.15:100095) Avail: NTIS HC A03/MF A01 CSCL 01A

Results from the Viscous Transonic Airfoil Workshop are compared with each other and with experimental data. Test cases used include attached and separated transonic flows for the NACA 0012 airfoil. A total of 23 sets of numerical results from 15 different author groups are included. The numerical method used vary widely and include: 16 Navier-Stokes methods, 2 Euler boundary layer methods, and 5 potential boundary layer methods. The results indicate a high degree of sophistication among the numerical methods with generally good agreement between the various computed and experimental results for attached or moderately separated cases. The agreement for cases with larger separation is only fair and suggests additional work is required in this area.

Author

N88-22010\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

## TRANSONIC NAVIER-STOKES COMPUTATIONS OF STRAKE-GENERATED VORTEX INTERACTIONS FOR A FIGHTER-LIKE CONFIGURATION

STEVE REZNICK Feb. 1988 117 p

(NASA-TM-100009; A-87288; NAS 1.15:100009) Avail: NTIS HC A06/MF A01 CSCL 01A

Transonic Euler/Navier-Stokes computations are accomplished for wing-body flow fields using a computer program called Transonic Navier-Stokes (TNS). The wing-body grids are generated using a program called ZONER, which subdivides a coarse grid about a fighter-like aircraft configuration into smaller zones, which are tailored to local grid requirements. These zones can be either finely clustered for capture of viscous effects, or coarsely clustered for inviscid portions of the flow field. Different equation sets may be solved in the different zone types. This modular approach also affords the opportunity to modify a local region of the grid without recomputing the global grid. This capability speeds up the design optimization process when quick modifications to the geometry definition are desired. The solution algorithm embodied in TNS is implicit, and is capable of capturing pressure gradients associated with shocks. The algebraic turbulence model employed has proven adequate for viscous interactions with moderate separation. Results confirm that the TNS program can successfully be used to simulate transonic viscous flows about complicated 3-D geometries.

Author

N88-22011\*# University of Southern California, Los Angeles. Dept. of Aerospace Engineering.

## PRESSURE MEASUREMENTS OF IMPINGING JET WITH ASYMMETRIC NOZZLE Progress Report

CHIH-MING HO May 1988 24 p

(Contract NAG1-819)

(NASA-CR-182759; NAS 1.26:182759) Avail: NTIS HC A03/MF A01 CSCL 01A

For modern aircraft, impinging surfaces are commonly used as a device for obtaining vector thrust from engine exhaust. The nature of dynamic loading is important to understand for design purposes. In this study, the frequency, mode, and level of pressure fluctuations generated by an elliptic jet are examined. The elliptic jet is used because it has several operational advantages over a circular jet.

N88-22012\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

## LASER VELOCIMETER MEASUREMENTS IN A WING-FUSELAGE TYPE JUNCTURE

J. SCHEIMAN and L. R. KUBENDRAN (Analytical Services and Materials, Inc., Hampton, Va.) Apr. 1988 9 p Presented at the IEEE 11th International Congress on Instrumentation in Aerospace Simulation Facilities, Stanford, Calif., 26-28 Aug. 1985 (NASA-TM-100588; NAS 1.15:100588) Avail: NTIS HC A02/MF A01 CSCL 01A

A single axis, five beam, three component laser velocimeter system was used in a juncture flow experiment. A description of the seeding system developed for and used in this experiment is given. The performanace of the LV system was evaluated, and some of the problems associated with it were identified. Satisfactory results were obtained in the juncture flow experiments using this LV system.

N88-22013\*# National Aeronautics and Space Administration.
Ames Research Center, Moffett Field, Calif.

### BOUNDARY-LAYER AND WAKE MEASUREMENTS ON A SWEPT, CIRCULATION-CONTROL WING

FRANK W. SPAID (McDonnell-Douglas Research Labs., St. Louis, Mo.) and EARL R. KEENER Dec. 1987 91 p Previously announced in IAA as A87-22449

(NASA-TM-89426; A-87098; NAS 1.15:89426) Avail: NTIS HC A05/MF A01 CSCL 01A

Wind-tunnel measurements of boundary-layer and wake velocity profiles and surface static pressure distributions are presented for

a swept, circulation-control wing. The model is an aspect-ratio-four semispan wing mounted on the tunnel side wall at a sweep angle deg. A full-span, tangential, rearward blowing, circulation-control slot is located ahead of the trailing edge on the upper surface. Flow surveys were obtained at mid-semispan at freestream Mach numbers of 0.425 and 0.70. Boundary-layer profiles measured on the forward portions of the wing are approximately streamwise and two dimensional. The flow in the vicinity of the jet exit and in the near wake is highly three dimensional. The jet flow near the slot on the Coanda surface is directed normal to the slot. Near-wake surveys show large outboard flows at the center of the wake. At Mach 0.425 and a 5-deg angle of attack, a range of jet-blowing rates was found for which an abrupt transition from incipient separation to attached flow occurs in the boundary layer upstream of the slot. The variation in the lower-surface separation location with blowing rate was determined from boundary-layer measurements at Mach 0.425.

Author

N88-22014\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

#### **BIFURCATIONS IN UNSTEADY**

#### **AERODYNAMICS-IMPLICATIONS FOR TESTING**

GARY T. CHAPMAN and MURRAY TOBAK Mar. 1988 20 p (NASA-TM-100083; A-88076; NAS 1.15:100083) Avail: NTIS HC A03/MF A01 CSCL 01A

The various forms of bifurcations that can occur between steady and unsteady aerodynamic flows are reviewed. Examples are provided to illustrate the various ways in which bifurcations may intervene to influence the outcome of dynamics tests involving unsteady aerodynamics. The presence of bifurcation phenomena in such tests must be taken into consideration to ensure the proper interpretation of results, and some recommendations are made to that end.

N88-22015\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

#### INFLOW MEASUREMENT MADE WITH A LASER VELOCIMETER ON A HELICOPTER MODEL IN FORWARD FLIGHT. VOLUME 3: RECTANGULAR PLANFORM BLADES AT AN ADVANCE RATIO OF 0.30

JOE W. ELLIOTT, SUSAN L. ALTHOFF, and RICHARD H. SAILEY (PRC Kentron, Inc., Hampton, Va.) Apr. 1988 390 p (NASA-TM-100543; NAS 1.15:100543; AVSCOM-TM-88-B-006) Avail: NTIS HC A17/MF A01 CSCL 01A

An experimental investigation was conducted in the 14- by 22-Foot Subsonic Tunnel at NASA Langley Research Center to measure the inflow into a scale model helicopter rotor in forward flight (micron sub infinity = 0.30). The measurements were made with a two component Laser Velocimeter (LV) one chord above the plane formed by the path of the rotor tips (tip path plane). A conditional sampling technique was employed to determine the azimuthal position of the rotor at the time that each velocity measurement was made so that the azimuthal fluctuations in velocity could be determined. Measurements were made at a total of 180 separate locations in order to clearly define the inflow character. These data are presented without analysis.

N88-22016\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

## PROCEDURES AND REQUIREMENTS FOR TESTING IN THE LANGLEY RESEARCH CENTER UNITARY PLAN WIND TUNNEL

DONALD L. WASSUM and CURTIS E. HYMAN, JR. (PRC Kentron, Inc., Hampton, Va.) Feb. 1988 53 p (NASA-TM-100529; NAS 1.15:100529) Avail: NTIS HC A04/MF

A01 CSCL 01A

Information is presented to assist those interested in conducting wind-tunnel testing within the Langley Unitary Plan Wind Tunnel. Procedures, requirements, forms and examples necessary for tunnel entry are included.

N88-22017# National Aerospace Lab., Amsterdam (Netherlands). Informatics Div.

TRENDS IN COMPUTATIONAL FLUID DYNAMICS (CFD) FOR AERONAUTICAL 3D STEADY APPLICATIONS: THE DUTCH SITUATION

J. W. BOERSTOEL, A. E. P. VELDMAN, J. VANDERVOOREN, and A. J. VANDERWEES 28 Jul. 1986 21 p Presented at the 25th Working Group on Computational Fluid Dynamics Meeting, Delft, The Netherlands, 20 Oct. 1986

(NLR-MP-86074-U; B8731726; ETN-88-92225) Avail: NTIS HC A03/MF A01

Developments in computational 3-D steady aerodynamics software focusing on the efficient aerodynamic design of the next generation of transport aircraft, are surveyed. The major aerodynamic problem areas accessible to computational aerodynamics are discussed. The coherence in computational methods development is explained by showing how the methods cover a growing part of the aircraft operating range. The development of the most advanced methods, based on the Euler and Reynolds-average Navier-Stokes equations, is outlined. Computing aspects are reviewed.

N88-22018\*# Southampton Univ. (England). Dept. of Aeronautics and Astronautics.

FLEXIWALL 3 SO: A SECOND ORDER PREDICTIVE STRATEGY FOR RAPID WALL ADJUSTMENT IN TWO-DIMENSIONAL COMPRESSIBLE FLOW

M. J. GOODYER and MICHAEL JUDD Jul. 1981 59 p (Contract NSG7-172)

(NASA-CR-181662; NAS 1.26:181662) Avail: NTIS HC A04/MF A01 CSCL 01A

An improvement is presented for the 2-D strategies for adjustment of the flexible top and bottom walls of an Adaptive (Wind Tunnel) Wall Test Section (AWTS). This adjustment is part of the wall adaptation process to eliminate top and bottom wall interference at the source. The improvements to account for second order effects are described in mathematical detail. It is intended that these improvements should further minimize the necessary iterations in the wall adaptation process. An associated computer program written in BASIC is presented and several test cases run with this program are discussed. The strategy performs well for a theoretical test case but when applied to experimental AWTS data some discrepancies in the adapted wall shapes are found.

**Author** 

N88-22019\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

POROUS WIND TUNNEL CORRECTIONS FOR COUNTERROTATION PROPELLER TESTING

GEORGE L. STEFKO and ROBERT J. JERACKI 1988 18 p Presented at the 15th Aerodynamic Testing Conference, San Diego, Calif., 18-20 May 1988; sponsored by AIAA

(NASA-TM-100873; E-4099; NAS 1.15:100873) Avail: NTIS HC A03/MF A01 CSCL 01B

Wind tunnel interference corrections have direct impact on measured propeller efficiency. A systematic series of wind tunnel tests was done in the porous-wall NASA Lewis 8- by 6-Foot Wind Tunnel to determine the wind tunnel interference corrections to the NASA Lewis counterrotation propeller test data. The test results were compared with calculations from a potential flow code to determine the interference corrections. At a Mach number of 0.8, the interference corrections resulted in a -0.008 Mach number correction which reduced the counterrotation propeller net efficiency data by 0.46 percent at the reduced Mach number. Additional wind tunnel tests were done to measure the effect of propeller thrust on wind tunnel wall interference. No wall interference corrections due to propeller thrust were found necessary for the high speed counterrotation propeller data obtained in the porous wall NASA Lewis 8- by 6-Foot Wind Tunnel.

N88-22241# Joint Publications Research Service, Arlington, Va. INVESTIGATION OF SIDE-WALL EFFECTS IN WIND TUNNEL WITH SUPERCRITICAL AIRFOIL TESTING Abstract Only

CHAO GAO In its JPRS Report: Science and Technology. China p 50 11 Dec. 1987 Transl. into ENGLISH from Lixue Xuebao (Beijing, Peoples Republic of China), v. 19, no. 4, Jul. 1987 p 381-386

Avail: NTIS HC A06/MF A01

An investigation is presented of the side-wall effect in a two dimensional transonic wind tunnel with side-wall boundary layer suction around the model. The span of the airfoil model used in the experiments is larger than the width of the test section. Therefore, the model can be shifted laterally and the streamwise pressure distribution for different spanwise sections can be obtained. The test results show that, for supercritical flow, the application of side-wall suction will result in an improvement of spanwise uniformity of aerodynamics and a downstream movement of the shock wave.

N88-22243# Joint Publications Research Service, Arlington, Va. THEORETICAL MODEL AND NUMERICAL SOLUTION FOR COMPRESSIBLE VISCOUS VORTEX CORES Abstract Only BINGQIU LIN In its JPRS Report: Science and Technology.

China p 59 11 Dec. 1987 Transl. into ENGLISH from Kongqidonglixue Xuebao (Mianyang, Peoples Republic of China), v. 5, no. 3, Sep. 1987 p 235-243 Original language document was announced in IAA as A88-14016

Avail: NTIS HC A06/MF A01

Based on the dimensional analysis, the parabolic equation of a compressible viscous vortex core was derived. A simpler numerical method described can be used to calculate the subsonic, transonic, and supersonic vortex motions. Numerical results for two examples are also shown, one for the expanding motion of the stable vortex and the other for the contracting motion of the stable vortex.

N88-22244# Joint Publications Research Service, Arlington, Va. MIXED DIRECT-INVERSE PROBLEM OF TRANSONIC CASCADE Abstract Only

WEI LIU and MENGYU SHEN In its JPRS Report: Science and Technology. China p 60 11 Dec. 1987 Transl. into ENGLISH from Kongqidonglixue Xuebao (Mianyang, Peoples Republic of China), v. 5, no. 3, Sep. 1987 p 244-250 Original language document was announced in IAA as A88-14017 Avail: NTIS HC A06/MF A01

A computational method is used to solve the mixed direct-inverse problem of a transonic plane cascade. It is based on the finite volume method and solves Euler equations directly. In effect the flow field in which shocks exist can be studied. The present method can be used in a wider range then the transonic relaxation method.

N88-22859# National Aerospace Lab., Tokyo (Japan).
DESIGN METHOD FOR LAMINAR FLOW CONTROL OF
TWO-DIMENSIONAL AIRFOILS IN INCOMPRESSIBLE FLOW.
NUMERICAL STUDY OF LFC DESIGN CONCEPTS

YOJI ISHIDA Nov. 1986 16 p In JAPANESE; ENGLISH summary

(DE88-751809; NAL-TR-920) Avail: NTIS (US Sales Only) HC A03

A laminar flow control technology aims to greatly reduct the frictional resistance on the airfoil surface by retaining the laminar flow by stabilizing the boundary layer on the surface of the airfoil by sucking. It is an effective procedure to prepare, by calculation, a few design concepts with excellent characteristics and to carry out an experimental verification. The calculation method is composed of boundary layers for laminar, translational, and turbulent flow. Calculation of boundary layers put basis on Kellers box scheme (differential decomposition methods of boundary layer equation), and criterion of transition point used Cebeci-Smith's algebraic model. Both continuous and discrete models were used for suction. Effect of frictional resistance reduction, effect of

dissipating suction, effect of sucking position, and hybrid laminar flow control were examined. This method seems useful for a parametric study of laminar flow control airfoil design.

N88-22860# Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Brunswick (West Germany). Abteilung Zellenaerodynamik.

A MULTILIFTING LINE METHOD AND ITS APPLICATION IN **DESIGN AND ANALYSIS OF NONPLANAR WING** CONFIGURATIONS Ph.D. Thesis - Technische Univ.,

Brunswick, Fed. Republic of Germany

KARL-HEINZ HORSTMANN Dec. 1987 148 p in GERMAN; **ENGLISH summary** 

(DFVLR-FB-87-51; ISSN-0171-1342; ETN-88-92323) Avail: NTIS HC A07/MF A01; DFVLR, VB-PL-DO, 90 60 58, 5000 Cologne, Fed. Republic of Germany, 45 DM

A calculation method for nonplanar wing geometries having discrete bound vortices at the 1/4-lines of panels is described. Instead of the discrete trailing vortices of the vortex lattice singularity model, a trailing vortex sheet having a continuously distributed vortex strength is employed. The bound vortex strength is a steady function of the spanwise position. This function is assumed to be parabolic on each panel, so the vortex strength of the trailing vortices has a linear behavior in spanwise direction. This singularity model is employed in an analysis and in a design method which allows the design of nonplanar wings having minimum induced drag. Calculations with different geometries show that the accuracy of the method for load distribution and induced drag is as good as that of lifting surface theories.

Technische Hogeschool, Delft (Netherlands). Faculty of Aerospace Engineering.

EXPERIMENTAL INVESTIGATION OF THE TRANSONIC FLOW

AT THE LEEWARD SIDE OF A DELTA WING AT HIGH

Z. M. HOUTMAN and W. J. BANNINK Aug. 1987 43 p (LR-518; B8733283; ETN-88-92461) Avail: NTIS HC A03/MF A01

The transonic flow field at the leeward side of a cropped delta wing with a sweep angle of 65 deg mounted on a cylindrical body having an ogival nose was studied at a free stream Mach number of 0.85 and at angles of incidence of 10 and 20 deg. Measurements show a complex flow containing dominant regions of vortices, embedded shock waves, and separations. In spite of the transonic flow and the presence of a body extending in front of the wing apex a large part of the flow field may be regarded as conical. At an incidence of 20 deg a strong shock wave is observed at 80 percent chord position terminating a region of locally supersonic flow; the shock stands across the wing symmetry plane but its actual shape is unknown. Evidence of a nonconical shock between the primary vortex and the wing surface, probably generated by the upstream influence of the cropped wing tips and of the trailing edge is obtained. Both shocks interfere quite strongly with the vortex system. Indications for a conical shock above the leading edge vortex are found.

N88-22862\*# Virginia Polytechnic Inst. and State Univ., Blacksburg. Dept. of Engineering Mechanics. A NUMERICAL MODEL OF UNSTEADY, SUBSONIC

**AEROELASTIC BEHAVIOR Ph.D Thesis** 

THOMAS W. STRGANAC Aug. 1987 123 p S NASA Original document contains color illustrations Sponsored by (NASA-TM-101126; NAS 1.15:101126) Avail: NTIS HC A06/MF A01 CSCL 01A

A method for predicting unsteady, subsonic aeroelastic responses was developed. The technique accounts for aerodynamic nonlinearities associated with angles of attack, vortex-dominated flow, static deformations, and unsteady behavior. The fluid and the wing together are treated as a single dynamical system, and the equations of motion for the structure and flow field are integrated simultaneously and interactively in the time domain. The method employs an iterative scheme based on a predictor-corrector technique. The aerodynamic loads

computed by the general unsteady vortex-lattice method and are determined simultaneously with the motion of the wing. Because the unsteady vortex-lattice method predicts the wake as part of the solution, the history of the motion is taken into account: hysteresis is predicted. Two models are used to demonstrate the technique: a rigid wing on an elastic support experiencing plunge and pitch about the elastic axis, and an elastic wing rigidly supported at the root chord experiencing spanwise bending and twisting. The method can be readily extended to account for structural nonlinearities and/or substitute aerodynamic load models. The time domain solution coupled with the unsteady vortex-lattice method provides the capability of graphically depicting wing and wake motion. Author

N88-22863\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

INFLOW MEASUREMENTS MADE WITH A LASER VELOCIMETER ON A HELICOPTER MODEL IN FORWARD FLIGHT. VOLUME 4: TAPERED PLANFORM BLADES AT AN **ADVANCE RATIO OF 0.15** 

SUSAN L. ALTHOFF, JOE W. ELLIOTT, and RICHARD H. SAILEY (PRC Kentron, Inc., Hampton, Va.) Apr. 1988 322 p Also includes floppy disk format

(NASA-TM-100544; AVSCOM-TM-88-B-007; NAS 1.15:100544)

Avail: NTIS HC A14/MF A01 CSCL 01A

An experimental investigation was conducted in the 14- by 22-Foot Subsonic Tunnel at NASA Langley Research Center to measure the inflow into the scale model helicopter rotor in forward flight (mu sub infinity = 0.15). The measurements were made with a two-component Laser Velocimeter (LV) one chord above the plane formed by the path of the rotor tips (tip path plane). A conditional sampling technique was employed to determine the position of the rotor at the time that each velocity measurement was made so that the azimuthal fluctuations in velocity could be determined. Measurements were made at a total of 146 separate locations in order to clearly define the inflow character. This data is presented herein without analysis. In order to increase the availability of the resulting data, both the mean and azimuthally dependent values are included as part of this report on two 5.25 inch floppy disks in MS-DOS format.

National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif. ON THE VALIDATION OF A CODE AND A TURBULENCE

MODEL APPROPRIATE TO CIRCULATION CONTROL

J. R. VIEGAS, M. W. RUBESIN, and R. W. MACCORMACK (Stanford Univ., Calif.) Apr. 1988 25 p (NASA-TM-100090; A-88127; NAS 1.15:100090) Avail: NTIS HC A03/MF A01 CSCL 01A

A computer code for calculating flow about a circulation control airfoil within a wind tunnel test section has been developed. This code is being validated for eventual use as an aid to design such airfoils. The concept of code validation being used is explained. The initial stages of the process have been accomplished. The present code has been applied to a low-subsonic, 2-D flow about a circulation control airfoil for which extensive data exist. Two basic turbulence models and variants thereof have been successfully introduced into the algorithm, the Baldwin-Lomax algebraic and the Jones-Launder two-equation models of turbulence. The variants include adding a history of the jet development for the algebraic model and adding streamwise curvature effects for both models. Numerical difficulties and difficulties in the validation process are discussed. Turbulence model and code improvements to proceed with the validation process are also discussed.

N88-22865\*# Southampton Univ. (England). AEROFOIL TESTING IN A SELF-STREAMLINING FLEXIBLE WALLED WIND TUNNEL Ph.D. Thesis - Jul. 1987 MARK CHARLES LEWIS Washington NASA May 1988 271 p

(Contract NSG-7172) (NASA-CR-4128; NAS 1.26:4128) Avail: NTIS HC A12/MF A01 CSCL 01A

Two-dimensional self-streamlining flexible walled test sections eliminate, as far as experimentally possible, the top and bottom wall interference effects in transonic airfoil testing. The test section sidewalls are rigid, while the impervious top and bottom walls are flexible and contoured to streamline shapes by a system of jacks, without reference to the airfoil model. The concept of wall contouring to eliminate or minimize test section boundary interference in 2-D testing was first demonstrated by NPL in England during the early 40's. The transonic streamlining strategy proposed, developed and used by NPL has been compared with several modern strategies. The NPL strategy has proved to be surprisingly good at providing a wall interference-free test environment, giving model performance indistinguishable from that obtained using the modern strategies over a wide range of test conditions. In all previous investigations the achievement of wall streamlining in flexible walled test sections has been limited to test sections up to those resulting in the model's shock just extending to a streamlined wall. This work however, has also successfully demonstrated the feasibility of 2-D wall streamlining at test conditions where both model shocks have reached and penetrated through their respective flexible walls. Appropriate streamlining procedures have been established and are uncomplicated, enabling flexible walled test sections to cope easily with these high transonic flows. Author

N88-22866\*# McDonnell Aircraft Co., St. Louis, Mo. PROPULSION AND AIRFRAME AERODYNAMIC INTERACTIONS OF SUPERSONIC V/STOL CONFIGURATIONS. VOLUME 1: WIND TUNNEL TEST PRESSURE DATA REPORT D. E. ZILZ and P. A. DEVEREAUX Sep. 1985 885 p (Contract NAS2-10791)

(NASA-CR-177343-VOL-1; NAS 1.26:177343-VOL-1) Avail: NTIS HC A99/MF E03 CSCL 01A

A wind tunnel model of a supersonic V/STOL fighter configuration has been tested to measure the aerodynamic interaction effects which can result from geometrically close-coupled propulsion system/airframe components. The approach was to configure the model to represent two different test techniques. One was a conventional test technique composed of two test modes. In the Flow-Through mode, absolute configuration aerodynamics are measured, including inlet/airframe interactions. In the Jet-Effects mode, incremental nozzle/airframe interactions are measured. The other test technique is a propulsion simulator approach, where a sub-scale, externally powered engine is mounted in the model. This allows proper measurement of inlet/airframe and nozzle/airframe interactions simultaneously. This is Volume 1 of 2: Wind Tunnel Test Pressure Data Report.

Author

N88-22867\*# McDonnell Aircraft Co., St. Louis, Mo.
PROPULSION AND AIRFRAME AERODYNAMIC
INTERACTIONS OF SUPERSONIC V/STOL CONFIGURATIONS.
VOLUME 2: WIND TUNNEL TEST FORCE AND MOMENT
DATA REPORT

D. E. ZILZ Sep. 1985 328 p (Contract NAS2-10791) (NASA-CR-177343-VOL-2; NAS 1.26:177343-VOL-2) Avail: NTIS HC A15/MF A01 CSCL 01A

A wind tunnel model of a supersonic V/STOL fighter configuration has been tested to measure the aerodynamic interaction effects which can result from geometrically close-coupled propulsion system/airframe components. The approach was to configure the model to represent two different test techniques. One was a conventional test technique composed of two test modes. In the Flow-Through mode, absolute configuration aerodynamics are measured, including inlet/airframe interactions. In the Jet-Effects mode, incremental nozzle/airframe interactions are measured. The other test technique is a propulsion simulator approach, where a sub-scale, externally powered engine is mounted in the model. This allows proper measurement of

inlet/airframe and nozzle/airframe interactions simultaneously. This is Volume 2 of 2: Wind Tunnel Test Force and Moment Data Report.

Author

N88-22868\*# McDonnell Aircraft Co., St. Louis, Mo.
PROPULSION AND AIRFRAME AERODYNAMIC
INTERACTIONS OF SUPERSONIC V/STOL CONFIGURATIONS.
VOLUME 4: SUMMARY Final Report

D. E. ZILZ, H. W. WALLACE, and P. E. HILEY Sep. 1985 88 p (Contract NAS2-10791)

A wind tunnel model of a supersonic V/STOL fighter configuration has been tested to measure the aerodynamic interaction effects which can result from geometrically close-coupled propulsion system/airframe components. The approach was to configure the model to represent two different test techniques. One was a conventional test technique composed of two test modes. In the Flow-Through mode, absolute configuration aerodynamics are measured, including inlet/airframe interactions. In the Jet-Effects mode, incremental nozzle/airframe interactions are measured. The other test technique is a propulsion simulator approach, where a sub-scale, externally powered engine is mounted in the model. This allows proper measurement of inlet/airframe and nozzle/airframe interactions simultaneously. This is Volume 4 of 4: Final Report- Summary.

N88-22869# Nagoya Univ. (Japan). Inst. of Plasma Physics. ANALYSIS FOR HIGH COMPRESSIBLE SUPERSONIC FLOW IN CONVERGING NOZZLE

KEISHIRO NIU and TAKAYUKI AOKI (Tokyo Inst. of Tech., Yokahama, Japan ) Feb. 1988 16 p (IPPJ-860; ISSN-0469-4732) Avail: NTIS HC A03/MF A01

In a converging nozzle, fluid is shown to be compressed to a very high density, especially in the supersonic region, if the initial Mach number of the fluid is large. Thus it is shown that spherical implosion can be used as a method to make high density materials.

Author

N88-22870# Michigan Univ., Ann Arbor. Dept. of Aerospace Engineering.

THE STRUCTURE OF SONIC UNDEREXPANDED TURBULENT AIR JETS IN STILL AIR Interim Report, 15 Jul. 1985 - 15 Aug. 1987

S. G. CHUECH, M. C. LAI, and G. M. FAETH Sep. 1987 118 p

(Contract N00014-85-K-0604)

Turbulent subsonic, sonic and underexpanded round air jets, in still air, were studied both theoretically and experimentally. The following measurements were made: shock-wave structure of the underexpanded jets, using flash and continuous schlieren photography; mean and fluctuating concentrations and mean static pressures, using laser-induced fluorescence; and mean and fluctuating streamwise velocities, using laser-Doppler anemometry. Analysis included: solution of the parabolized Navier-Stokes equations of motion; and use of effective adapted-jet exit conditions, to avoid the complexities of treating shock-containing near field region of underexpanded jets. In both cases, turbulence properties were found using a k-epsilon turbulence model. Structure of the near-field region of the underexpanded jets was influenced by compressibility and turbulence levels at the jet exit. Mixing rates were reduced by compressibility when convective Mach numbers were greater than 0.5, in agreement with observations of Papamoschou and Roshko (1986); while increased turbulence levels at the jet exit increased mixing rates, which is a well-recognized effect for subsonic jets. The present parabolized Navier-Stokes method was successful for treating slug-flow exit conditions, but must be extended to treat effects of turbulent jet exit conditions.

N88-22874# JAI Associates, Mountain View, Calif.
TIP VORTICES OF ISOLATED WINGS AND HELICOPTER
ROTOR BLADES Final Report, Nov. 1984 - Nov. 1987
GANAPATHI R. SRINIVASAN Dec. 1987 86 p
(Contract DAAG29-85-C-0002)

Thin layer Navier-Stokes equations are solved numerically for simulating the flowfields of isolated wings and helicopter rotor blades with a particular emphasis on understanding the formation and roll-up of tip vortices in subsonic and transonic flows. Several test cases consisting of wings and rotor blades of different planforms have been considered to examine the influence of the tip-cap shape, the tip-planform, the freestream Mach number, and the effect of centrifugal forces of rotation. A fairly good definition of the formation and roll-up of the tip vortex is demonstrated for all the cases considered here. Finally, the calculated lift, drag and pitching-moment coefficients agree well with the experimentally determined values, where available. Alternate methods of simulating the hovering rotor flowfields in blade-fixed mode that have the circulation distribution as hovering blade are explored.

N88-22875# Dayton Univ., Ohio. Research Inst.
AN INTEGRAL EQUATION FOR THE LINEARIZED
SUPERSONIC FLOW OVER A WING Interim Report, Nov. 1986
- Aug. 1987

KARL G. GUDERLEY Feb. 1988 112 p

The results and discussion are presented.

(Contract F33615-86-C-3200)

(AD-A191408; UDR-TR-87-91; AFWAL-TR-87-3097) Avail: NTIS HC A06/MF A01 CSCL 01A

In the first formulation, the integral equation for linearized steady supersonic flows appears in a form where it is necessary to approach the planform from above or below by a limiting process. In the present report, the problem is transformed analytically in such a manner that this limiting process no longer appears and that the resulting expressions are numerically tractable. It is believed that such a formulation gives more freedom to take the particularities of a given problem into account. The formulation is applied to compute the conical field which arises at the top of an airfoil. A possible numerical approach to the solution of the integral equation in the general case is described, but only in a rough outline.

N88-23245\*# Purdue Univ., West Lafayette, Ind. School of Aeronautics and Astronautics.

## THE 2-D AND 3-D TIME MARCHING TRANSONIC POTENTIAL FLOW METHOD FOR PROPFANS

MARC H. WILLIAMS In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 263-271 May 1988 (Contract NAG3-499)

Avail: NTIS HC A20/MF A01 CSCL 01A

Recent efforts concentrated on the development of aerodynamic tools for the analysis of rotors at transonic speeds and of configurations involving relative rotation. Three distinct approaches were taken: (1) extension of the lifting surface method of Williams and Hwang (1986) to relative rotation; (2) development of a time marching linear potential method for counter rotation; and (3) development of 2 and 3 dimensional finite volume potential flow schemes for single rotation. Results from each of these approaches are described.

N88-23246\*# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

### PROPFAN MODEL WIND TUNNEL AEROELASTIC RESEARCH RESULTS

ORAL MEHMED *In* NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 273-286 May 1988

Avail: NTIS HC A20/MF A01 CSCL 01A

Some of the single rotation propfan model wind tunnel aeroelastic findings from the experimental part of this research

program are described. These findings include results for unstalled or classical flutter, blade response from separated flow excitations, and blade response from aerodynamic excitations at angled inflow conditions.

Author

N88-23248\*# Duke Univ., Durham, N. C. Dept. of Mechanical Engineering and Materials Science.

### REDUCED ORDER MODELS FOR NONLINEAR AERODYNAMICS

APARAJIT J. MAHAJAN, EARL H. DOWELL, and DONALD B. BLISS In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 299-308 May 1988

(Contract NAG3-724)

Avail: NTIS HC A20/MF A01 CSCL 01A

Reduced order models are needed for reliable, efficient and accurate prediction of aerodynamic forces to analyze fluid structure interaction problems in turbomachinery, including propfans. Here, a finite difference, time marching Navier-Stokes code is validated for unsteady airfoil motion by comparing results with those from classical potential flow. The Navier-Stokes code is then analyzed for calculation of primitive and exact estimates of eigenvalues and eigenvectors associated with fluid-airfoil interaction. A variational formulation for the Euler equations and Navier-Stokes equations will be the basis for reduction of order through an eigenvector transformation.

03

#### AIR TRANSPORTATION AND SAFETY

Includes passenger and cargo air transport operations; and aircraft accidents.

**A88-37226\*** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

### CIVIL APPLICATIONS OF HIGH SPEED ROTORCRAFT AND POWERED LIFT AIRCRAFT CONFIGURATIONS

JAMES A. ALBERS and JOHN ZUK (NASA, Ames Research Center, Moffett Field, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 627-651. Previously announced in STAR as N88-11643. refs

(SAE PAPER 872372)

Advanced subsonic vertical and short takeoff and landing (V/STOL) aircraft configurations offer new transportation options for civil applications. Described is a range of vehicles from low-disk to high-disk loading aircraft, including high-speed rotorcraft, V/STOL aircraft, and short takeoff and landing (STOL) aircraft. The status and advantages of the various configurations are described. Some of these show promise for relieving congestion in high population-density regions and providing transportation opportunities for low population-density regions.

#### A88-37227

### POWERED-LIFT TRANSPORT AIRCRAFT CERTIFICATION CRITERIA STATUS

LARRY B. ANDRIESEN and JIM S. HONAKER (FAA, Fort Worth, TX) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 653-655. (SAE PAPER 872376)

The development of FAA airworthiness certification standards for powered-lift aircraft is discussed, with emphasis on the tilt-rotor design. It is noted that the December 1986 powered lift draft criteria did not include standards for fly-by-wire and sidesticks. Difficulties in defining propulsion system failure include determining where the propulsion system starts and ends and what part of the propulsion system (engine, propeller, rotor, cross-shafting or

remote thrust-producers used for control, etc.) can fail. The draft criteria did not include necessary requirements for handling qualities in the vertical axis.

#### A88-38756# HELICOPTER AEROBATIC FLIGHT - THE TACTICAL **SIGNIFICANCE**

CHARLES A. PARLIER (McDonnell Douglas Helicopter Co., Mesa, AZ) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 486-494. refs (AIAA PAPER 88-2190)

While such state-of-the-art helicopters as the AH-64A have demonstrated significant aerobatic flight capability, as required for air-to-air combat, evidence of as-yet untapped maneuvering potential has emerged. Attention is given to capabilities for build-up/abort maneuvers, rolling, split-S, hammerhead, skewed loop, and loop maneuvers, and aerial combat in close-range encounters where there is little time for the pilot to react. Criteria for tactical high-angle maneuvering and the training requirements they suggest are discussed.

N88-22020# National Transportation Safety Board, Washington, D. C. Bureau of Field Operations.

AIRCRAFT ACCIDENT REPORTS, BRIEF FORMAT, US CIVIL AND FOREIGN AVIATION, ISSUE NUMBER 10 OF 1986 **ACCIDENTS** 

31 Dec. 1987 421 p

(PB87-916912; NTSB/AAB-87/12) Avail: NTIS HC A01/MF A01; also available on subscription, North American Continent HC \$185.00/year; all others write for quote CSCL 01C

The publication contains selected aircraft accident reports in Brief Format ocurring in U.S. civil and foreign aviation operations during Calendar Year 1986. Approximately 200 General Aviation and Air Carrier accidents contained in the publication represent a random selection. The publication is issued irregularly, normally eighteen times each year. The Brief Format represents the facts, conditions, circumstances, and probable cause(s) for each accident.

N88-22021# National Transportation Safety Board, Washington, D. C. Bureau of Accident Investigation.

AIRCRAFT ACCIDENT REPORT: NORTH STAR AVIATION, INC., PA-32 RT-300, N39614 AND ALAMEDA AERO CLUB CESSNA 172, N75584, OAKLAND, CALIFORNIA, MARCH 31, 1987

27 Oct. 1987 46 p

(PB87-910412; NTSB/AAR-87/09) Avail: NTIS HC A03/MF A01; also available on subscription, North American Continent HC \$60.00/year; all others write for quote CSCL 01C

The National Transportation Safety Board determines that the probable cause of the accident was the failure of each pilot-in-command to see and avoid the other aircraft, and the failure of the local controller to perceive the traffic conflict and issue traffic advisories. Contributing to the accident was the reduction in airspace separation between arriving and departing aircraft at Oakland's north field runways caused by the failure of the FAA to exercise its authority over airspace management. GRA

Deutsche Forschungs- und Versuchsanstalt fuer N88-22876# Luft- und Raumfahrt, Oberpfaffenhofen (West Germany). Abteilung Meteorologisch Fernerkundung.

BIBLIOGRAPHY OF ICING ON AIRCRAFT (STATUS 1987) Oct. 1987 KLAUS-PETER SCHICKEL and WERNER FUCHS 38 p In GERMAN; ENGLISH summary

(DFVLR-MITT-87-18; ISSN-0176-7739; ETN-88-92310) Avail: NTIS HC A03/MF A01; DFVLR, VB-PL-DO, 90 60 58, 5000 Cologne, Fed. Republic of Germany, 12.50 DM

Over 140 references on aircraft icing, particularly helicopters, are presented. The contributions of satellite imagery and personal computers to forecasting cloud icing and aircraft icing is stressed.

N88-22877# National Transportation Safety Board, Washington, D. C. Bureau of Accident Investigation.

AIRCRAFT ACCIDENT REPORT: MIDAIR COLLISION OF US ARMY U-21A, ARMY 18061 AND SACHS ELECTRIC COMPANY PIPER PA-31-350, N60SE, INDEPENDENCE, MISSOURI, **JANUARY 20, 1987** 

3 Feb. 1988 61 p

(PB88-910401; NTSB-AAR-88-01) Avail: NTIS HC A04/MF A01; also available on subscription, North American Continent HC \$70.00/year; all others write for quote CSCL 01C

The National Transportation Safety Board determines that the probable cause of the accident was the failure of the radar controllers to detect the conflict and to issue traffic advisories or a safety alert to the flightcrew of the U-21; deficiencies of the see and avoid concept as a primary means of collision avoidance; and the lack of automated redundancy in the air traffic control system to provide conflict detection between participating and nonparticipating aircraft.

N88-22878# National Transportation Safety Board, Washington, D. C. Bureau of Accident Investigation.

AIRCRAFT ACCIDENT/INCIDENT SUMMARY REPORTS: MODENA, PENNSYLVANIA, MARCH 17, 1986; REDWATER, TEXAS, APRIL 4, 1986

20 Mar. 1988 19 p

(PB88-910403; NTSB-AAR-88-01-SUMM) Avail: NTIS HC A03/MF A01 CSCL 09C

This publication is a compilation of the reports of two separate aircraft accidents investigated by the National Transportation Safety Board. The accident locations and their dates are as follows: Modena, Pennsylvania, March 17, 1986, and Redwater, Texas, April 4, 1986.

#### 04

#### AIRCRAFT COMMUNICATIONS AND NAVIGATION

Includes digital and voice communication with aircraft; air navigation systems (satellite and ground based); and air traffic control.

#### A88-37376

INSTITUTE OF NAVIGATION, TECHNICAL MEETING, 1ST, COLORADO SPRINGS, CO, SEPT. 21-25, 1987, PROCEEDINGS Meeting sponsored by the Institute of Navigation. Washington, DC, Institute of Navigation, 1987, 320 p. For individual items see A88-37377 to A88-37413.

Papers are presented on GPS phase III multichannel user equipment, GPS accuracy performance tests, and software architecture of the family of DOD standard GPS receivers. Also considered are a GPS hover position sensing system, GPS applications to carrier-based naval aircraft, and a potential GPS user architecture for the NASA Space Station based on Landsat 4/5 experience. Other topics include GPS integration with a low-cost inertial navigation unit, an integrated GPS/IRS design approach, and differential GPS with a sequencing receiver. Papers are also presented on a Kalman filter approach to self-contained GPS failure detection, receiver autonomous integrity monitoring using a 24-satellite GPS constellation, and GPS integrity monitoring for commercial applications using an IRS as a reference.

#### A88-37377#

#### GPS OVERVIEW -THE OPERATOR'S PERSPECTIVE

OWEN E. JENSEN (USAF, Washington, DC) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 1-3.

Maintenance of the Navstar GPS global navigation service by the USAF is discussed, in addition to shortcomings of the system. It is suggested that the USAF will provide periodic reports on the status of the entire system, identifying not only predicted areas of reduced accuracy, but those areas effected by unforeseen spacecraft degradation as well. Projected uses of the GPS are discussed, such as reducing the time required for position location in geodetic applications and the performing of global surveys.

R.R

#### A88-37378#

#### GPS PHASE III MULTI-CHANNEL USER EQUIPMENT

J. F. VACHERLON, A. C. HUNEKE, G. M. KAISER, D. C. FORSETH, and J. H. JUSTICE (Rockwell International Corp., Collins Government Avionics Div., Cedar Rapids, IA) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 4-13. refs

The architecture of the multichannel GPS Phase III receivers, based on low-risk modifications to the Phase IIB design which are intended to improve system integration flexiblity, life cycle cost, and producibility, is discussed. The present receivers are based on five variations of a basic 2-channel and 5-channel P-code design with flexible I/O capability, and they can accommodate the integration needs of over 75 host vehicle applications. A unique stack-oriented adaptive processing system processor and complete selective availability/antispoofing capabilities are included in the system. Technology upgrades include the incorporation of low-power logic and the use of denser memory.

#### A88-37379#

# FEATURES AND CAPABILITIES OF THE DOD STANDARD GPS RECEIVERS FOR AIRCRAFT AND SEABORNE APPLICATIONS

G. KRISHNAMURTI and D. E. GRAY (Rockwell International Corp., Cedar Rapids, IA) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 14-22.

The operational capabilities, interfaces, and integration options provided by two 5-channel GPS receivers developed for aircraft and seaborne applications are discussed. Both receivers provide high-accuracy navigation solutions in both the aided and unaided modes and low time to first fixes under adverse jamming and dynamic conditions. Full denial of accuracy and antispoofing capabilites are included. High-accuracy time outputs and a complete area navigation function, including a rendezvous mode and mark capability with storage capacity for 209 waypoints, are provided by the receivers. The receivers also include comprehensive fault detection and isolation capabilities.

#### A88-37385#

#### RESULTS OF DYNAMIC TESTING OF THE USAF/ESMC GPS USER EQUIPMENT ABOARD THE RANGE TRACKING SHIPS USNS OBSERVATION ISLAND AND USNS REDSTONE

ANDREW NELSON (Pan Am World Services, Inc., Patrick AFB, FL) and EDWARD FRENCH (RCA International Service Co., Patrick AFB, FL) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 62-71. refs

Two systems consisting of a GPS receiver, navigational computer, and associated data recording devices and electronics for providing accurate positioning of the instrumentation ships USNS Redstone and USNS Observation Island are described. The positional accuracy of the Redstone and Observation Island GPS user equipment during multispacecraft coverage with good geometries was evaluated using a DM-43 autotape system as a reference. It is noted that initial positioning solutions using two or three space vehicles at the beginning of a tracking window are not presently within the + or - 15 m specifications in latitude and longitude due to an unsettled Kalman filter.

#### A88-37386#

### REFERENCE TRAJECTORIES FROM GPS MEASUREMENTS JAMES E. ROBBINS (General Dynamics Services Co., Yuma, AZ)

JAMES E. ROBBINS (General Dynamics Services Co., Yuma, AZ) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC,

Institute of Navigation, 1987, p. 72-80. USAF-sponsored research.

Reference trajectories for vehicles for which GPS measurements are available are determined which can be used a reference for the evaluation of GPS user-equipment and integrated host vehicle navigation. Three GPS solutions have been used in obtaining the reference trajectories: (1) a closed-form solution of the GPS pseudorange equations; (2) an unaided Kalman filter; and (3) an inertially-aided Kalman filter. It is noted that all of the solutions operate with or without differential GPS. Observed rms differences between the present system and the Yuma proving ground laser tracking system demonstrate that the system and the lasers both have at least a 5-m rms accuracy.

#### A88-37390#

#### A GPS HOVER POSITION SENSING SYSTEM

KEVIN C. SCHLOSSER and REX HOWE (U.S. Army, Aviation Systems Command, Fort Monmouth, NJ) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 103-108.

The test set up and results for an integrated GPS/inertial hover position sensing system are discussed. Initial flight test data suggest that the required hover position sensor accuracy is achievable using an integrated GPS/inertial system provided that modifications are made to the standard GPS navigation algorithms. Results point to the need for the GPS satellite selection algorithm to lock on to a constellation for the entire duration of the hover. Error growth due to ionospheric drift was noted over the three to four minute hover duration.

#### A88-37393#

### A DIGITAL P-CODE GPS RECIEVER AND ITS APPLICATIONS TO EMBEDDED SYSTEMS

A. J. VAN DIERENDONCK, C. E. HEGER, D. C. WESTCOTT, and Q. D. HUA (Stanford Telecommunications, Inc., Santa Clara, CA) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 130-139.

A GPS P-code receiver/navigator board set is described which can be used for embedding the GPS capability within other navigation systems or sensors, or in other avionics systems. The present high-performance digital design includes VLSI and surface acoustic wave technology, resulting in small size, reduced power dissipation, higher reliability, and lower cost. The use of VLSI also eliminates many implementation losses characteristic of analog, analog-digital, and other digital designs. The present receiver uses multiple correlators (three or more) in the receiver channels.

R.R.

#### A88-37394#

### THE CANADIAN MARCONI COMPANY GPS RECEIVER - ITS DEVELOPMENT, TEST, AND FUTURE

PATRICK J. HUI and JAMES M. BROWN (Canadian Marconi Co., Kanata, Canada) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 140-149. refs

The design methodology, design trade-offs, and equipment features of the CMA-786, a GPS navigation system using the Navstar/GPS standard positioning service, are described. The system is capable of acquiring and tracking the coarse-acquisition code from all satellites on the L1 (1575.42 MHz) frequency band. The CMA-786 design is based on a dual signal-processing system architecture, and the receiver uses an adaptive satellite sequencing scheme. The various modules are described in detail, along with the CMA-786 software. Flight testing of the system resulted in both a software upgrade and the replacement of the least squares filter with a Kalman filter.

A88-37397\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

HELICOPTER TERMINAL APPROACH USING DIFFERENTIAL GPS WITH VERTICAL-AXIS ENHANCEMENT

F. G. EDWARDS, R. A. PAIELLI, and D. M. HEGARTY (NASA, IN: Institute of Ames Research Center, Moffett Field, CA) Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 163-170. refs

The NAVSTAR Global Positioning System (GPS) in differential mode (DGPS) has been shown to be least accurate in the vertical axis. The vertical axis also has the most stringent accuracy requirements for aircraft precision approach and landing. A series of flight tests were conducted to evaluate a concept for improving the DGPS vertical axis navigation performance. These tests incorporated augmentation sensors to aid the DGPS navigation solution during terminal approach operations. A GPS receiver was installed on board a NASA helicopter and interfaced with a real-time digital computer system. A reconfigurable navigation filter programmed in the digital computer provided an augmented DGPS solution, with selectable inputs from a low-cost vertical accelerometer, a barometric altimeter, and the aircraft attitude gyros. The reference aircraft position was determined by a laser tracker. Extensive post-test analysis was done to optimize the filter performance during the terminal approach operation. Test results show that baro-altimeter aiding can significantly improve vertical axis performance. Follow-on tests are planned for the Author optimized configurations.

#### A88-37399# INTEGRATION OF GPS RECEIVERS INTO EXISTING **INERTIAL NAVIGATION SYSTEMS**

D. A. TAZARTES and J. G. MARK (Litton Industries, Guidance and Control Systems Div., Woodland Hills, CA) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 176-183. refs

Many inertial navigation systems of both platform and ring laser strapdown types are currently in service. This paper discusses the possibility and desirability of incorporating a small GPS receiver in these systems. Advances in technology such as microprocessors, gate arrays and surface mount devices allow the existing INS electronics to be replaced in a reduced volume. The remaining space in many cases is sufficient to permit the insertion of a small GPS Receiver. Locating the GPS receiver in an inertial navigation system (INS) solves many of the usual system integration problems. Tight coupling between the GPS and INS can be achieved since data latency is minimized and well controlled. In such a configuration, rate aiding of the GPS is easily achieved. This approach also leads to greater flexibility and enhanced overall performance since all GPS and INS data are simultaneously available. While not providing the ultimate in redundancy, the integrated INS/GPS approach does offer greater simplicity with enhanced performance. This makes it a very attractive solution.

Author

#### A88-37400# A FULLY INTEGRATED GPS/DOPPLER/INERTIAL **NAVIGATION SYSTEM**

STEPHEN F. ROUNDS and JEAN M. CASEY (Singer Co., Electronic Systems Div., Wayne, NJ) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p.

The ability of a Doppler system integrated with a GPS/inertial system to maintain system accuracy during periods of GPS outage has been demonstrated. Doppler system modelling is considered, in addition to the use of GPS/inertial data to calibrate the elements of the model using a Kalman filter. Trade-off studies on the use of a Doppler system vs the use of a higher accuracy INS indicate that the addition of the Doppler may be approximately equivalent to an INS improvement of 60 percent.

#### A88-37402#

GPS INTEGRATION WITH LOW-COST INERTIAL NAVIGATION

DONALD T. KNIGHT (Magnavox Advanced Products and Systems

Co., Torrance, CA) IN: Institute of Navigation, Technical Meeting, 1st. Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 197-203.

A successful integration is described that involves a one-channel GPS receiver tightly coupled with a low-cost inertial navigation unit (INU). The combination is intended for low cost military applications. A 17-state Kalman navigation filter was used that performs in-flight calibration and alignment of the INU using GPS receiver measurements of pseudorange and delta range. By including INU gyro and accelerometer error states in the Kalman filter, the low-cost INU performs as well as units costing much more. Conversely, INU velocity data is used to extend the GPS receiver tracking threshold against jammers, and to improve reacquisition of signals after a loss. Sensor error models, Kalman filter design and system-level performance predictions are briefly described. Field test methodology is described, and field test results obtained to date are presented.

#### A88-37403#

#### T-33 AIRCRAFT DEMONSTRATION OF GPS AIDED INERTIAL NAVIGATION

DAVID E. FRAZIER, EUGENE A. MICKLE, JOHN T. NIELSON, and KENNETH W. RIGG (Boeing Aerospace Co., Seattle, WA) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 204-211.

A Boeing Aerospace Company research project has been completed in which a single channel GPS receiver was integrated with a high quality inertial navigation system (INS). Aiding from the INS and a barometric altimeter was implemented to enable the GPS receiver to withstand satellite signal outages. Aiding also enabled the single channel receiver to be initialized during flight and to navigate using three satellites instead of four, as are normally required. The high quality INS provided good performance during extended periods of satellite outage. The resulting system has better accuracy than GPS alone as well as the jam immunity and responsiveness of inertial navigation. System tests were conducted in a Boeing-owned T-33 jet aircraft in Western Washington and at Yuma Proving Grounds. Earlier development and test activities were conducted in a mobile avionics lab, (a modified Greyhound bus). This effort is different from others, including earlier efforts by Boeing, in that it represents the first time that a single channel receiver has been flown at Yuma. The results support our assertion that a single channel receiver using INS aiding can perform as well as an unaided five channel set in a dynamic environment.

Author

#### A88-37404#

#### AN INTEGRATED GPS/IRS DESIGN APPROACH

RANDOLPH G. HARTMAN (Honeywell, Inc., Air Transport Div., IN: Institute of Navigation, Technical Saint Louis Park, MN) Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p.

The design approach and advantages of GPS/inertial reference system integration are discussed. Advantages of the integrated approach include enhanced satellite tracking, inertial vertical loop stabilization, GPS navigation during poor satellite coverage, in-flight inertial alignment, and reduced synchronization errors. The components of the system, a GPS antenna, a two-channel sequential GPS preprocesssing module, and a strapdown Schuler tuned laser inertial reference unit, are described in detail. Other topics discussed include GPS preprocessor software processing, satellite management, autonomous and hybrid GPS navigation, and inertial navigation software processing.

#### A88-37405#

#### INTEGRATION OF DIFFERENTIAL GPS WITH INS FOR PRECISE POSITION, ATTITUDE AND AZIMUTH **DETERMINATION**

A. K. AGGARWAL (Magnavox Advanced Products and Systems Co., Torrance, CA) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 220-227. Research sponsored by the McDonnell Douglas Astronautics Co. refs

The NAVSTAR Global Positioning System (GPS), currently being developed for the Department of Defense, is a space-based navigation system that will provide the user with precise position, velocity and time information on a 24-hour basis and in all-weather conditions at any point on the globe. Differential operation,, wherein a high quality, surveyed-in receiver installation determines satellite pseudorange errors and communicates them to nearby users, offers a promising technique for further improving the GPS position accuracy on a local scale. A GPS receiver, under differential operation and when integrated with an Inertial Measurement Unit (IMU) provides a very high quality navigation system for a variety of applications. The resulting navigation system overcomes many of the weaknesses of a stand-alone GPS or IMU by providing: (1) high rate/accuracy position and velocity estimates during dynamics, (2) the reduced position and velocity error growth during GPS signal outage, (3) improved jamming resistance through code loop aiding, and (4) the availability of very precise attitude and azimuth of the vehicle. This makes the Differential GPS/INS suitable for truth navigation systems, for calibration, and instrumentation.

Author

#### A88-37406#

#### DIFFERENTIAL GPS WITH A SEQUENCING RECEIVER

RALPH ESCHENBACH and ANIL TIWARI (Trimble Navigation, Sunnyvale, CA) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 228-234.

Differential GPS tests have been conducted with a 10X GPS/Loran receiver modified to accept Radio Technical Commission for Maritime Service data. The 10X has a two-channel sequencing GPS receiver. Tests conducted for both zero and 12 meter baseline conditions show a mean position error of about 2 m with an rms of less than 3 m. It is noted that satellite switching had little effect on the performance of differential GPS, and that the Delta differential connections provided by the reference station made the ephemeris transition transparent to the user.

#### A88-37412#

### GPS INTEGRITY MONITORING FOR COMMERCIAL APPLICATIONS USING AN IRS AS A REFERENCE

MATS A. BRENNER (Honeywell Inc., Air Transport Systems Div., Saint Louis Park, MN) IN: Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings. Washington, DC, Institute of Navigation, 1987, p. 277-286.

An integrated GPS/inertial reference system (IRS) approach for integrity monitoring in commercial applications is presented, with special attention being given to the soft-type failure (failures that cause the error in pseudorange to grow slowly). Simulation results provide values for the smallest detectable drift in pseudorange. Crucial factors which effect the performance are shown to be the time between update of the satellite health status and the selective availablity noise. If soft failure occurs in a satellite for which no redundant satellite information is available, the GPS/IRS Kalman filter will detect the failure using statistical data describing the error in measured pseudorange or delta-range values.

#### A88-37699

# RADIO-ELECTRONIC EQUIPMENT OF AIRCRAFT: HANDBOOK [RADIOELEKTRONNOE OBORUDOVANIE LETATEL'NYKH APPARATOV: SPRAVOCHNIK]

ANDREI ANAN'EVICH SOSNOVSKII and IZIDOR ARONOVICH KHAIMOVICH Moscow, Izdatel'stvo Transport, 1987, 256 p. In Russian. refs

The functions of the radio-electronic equipment of commercial aircraft, the factors determining the makeup of the equipment, and the principles of combining components in equipment complexes are discussed. Detailed data are presented on communication, navigation, landing, and traffic control systems and

their components. Particular attention is given to the principle of operation, technical characteristics and parameters, architecture, and the overall design and layout of airborne radio-electronic systems.

V.L.

#### A88-38705#

### RADARBET - A MULTIPLE TRAJECTORY ESTIMATOR USING AN EXPERT SYSTEM

L. A. SLEDJESKI and L. S. STONE (Grumman Data Systems Corp., Bethpage, NY) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 28-35.

(AIAA PAPER 88-2082)

'Radarbet', a nine-state Kalman filter-based trajectory estimator operating in real time for flight test applications, furnishes accurate trajectory data representing mission spatial positions, velocities, and accelerations for up to eight different aircraft simultaneously. These trajectory estimates can not only drive geographical displays, but will also provide real-time checkout of onboard navigation, radar, and weapons systems. Radarbet incorporates highly flexible mission reconfiguration capabilities. Operator interaction is kept to a minimum through the use of a high-level color graphics display and a rule-based expert system for real-time maintenance and filter stabilization.

#### A88-38714#

#### FLIGHT TEST IMAGERY - GETTING MORE FOR LESS

VAL D. VAUGHN and ROBERT A. LINDSAY (Unisys Corp., Defense Systems Div., Salt Lake City, UT) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 118-126. refs (AIAA PAPER 88-2102)

An account is given of image compression techniques for the transmission of TV-quality real-time imagery, with a view to the achievable compression performance and the nature of hardware implementation problems. Attention is given to the vector quantization of imagery, outlining its implementation parameters for the case of an airborne image compression system that can transmit TV-quality video at rates as low as 1-15 Mbps. Implementation results are presented for an operating breadboard vector quantization system.

#### A88-38720#

### JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM (JTIDS) CLASS 2 TERMINAL FLIGHT TEST

S. J. DOBRONSKI (McDonnell Aircraft Co., Saint Louis, MO) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 162-170. refs (AIAA PAPER 88-2119)

The DOD's Joint Tactical Information Distribution System (JTIDS) for improving the tactical coordination of U.S. forces furnishes users with selective information distribution, digital voice, relative navigation, hostile/friendly/unknown aircraft locations, and aircraft identification capabilities. JTIDS is a secure and jam-resistant TDMA system implemented through two classes of terminals. Attention is given to flight test results for the Class 2 Terminals, designed for use aboard ships, tactical aircraft, and mobile ground units.

#### A88-38726#

### A NEW METHOD TO CONFIRM CATEGORY III AUTOLAND PERFORMANCE

HAROLD K. CHENEY and CANH T. PHAM (Douglas Aircraft Co., Long Beach, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 219-223.

(AIAA PAPER 88-2126)

Flight testing and certification of Category III autoland systems require the measurement of touchdown positions for numerous

landings. XILS, a new computerized flight-test procedure, has been developed to efficiently calculate an aircraft's position during an instrument landing system (ILS) landing and rollout. This method uses glide slope and localizer deviations, radio altitude, inertial reference system (IRS) ground speed, and ILS geometry. It provides data of the longitudinal distance from the glide slope transmitter and lateral distance from the localizer beam's centerline. The input data needed to make the calculations are recorded on the test aircraft's data tape. The test method described has been successfully used to confirm Part 25 Category III autoland performance, and is faster and less expensive for obtaining previous flight-test performance data than autoland position-tracking procedures. This paper presents the equations and validation methods used by Douglas Aircraft Company to establish the procedure for autoland flight testing.

#### A88-38743# AN AIRBORNE REALTIME DATA PROCESSING AND MONITORING SYSTEM FOR RESEARCH AIRCRAFT

A. REDEKER and P. VOERSMANN (Aerodata Flugmesstechnik GmbH, Brunswick, Federal Republic of Germany) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 361-367.

(AIAA PAPER 88-2165)

The paper presents the concept and realization of an open data system for airborne applications. It was layed out for the requirements of research aircraft, where sensor configurations and measuring instruments are varying from one experiment to another. All users have access to a pool of common sensor- and software resources. Special hard- and software interfaces have been defined for users to bring in their private sensor signals and computation algorithms. The system is suited for realtime processing, recording, and on-line monitoring of sensor data. It is the aim of the system design to enable the operator to perform quick error detection as well as to optimize flight conditions for an experiment. Examples for meteorological, flight-mechanical, and air-chemical applications Author are given.

#### A88-39135

### ILS GLIDESCOPE EVALUATION OF IMPERFECT TERRAIN

M. M. POULOSE (National Airports Authority of India, Bangalore) and P. R. MAHAPATRA (Indian Institute of Science, Bangalore, India) IEEE Transactions on Aerospace and Electronics Systems (ISSN 0018-9251), vol. 24, March 1988, p. 186-191. refs

Instrument landing systems (ILS) are normally designed assuming the site around them to be flat. Uneven terrain results in undulations in the glidescope. In recent years, models have been evolved for predicting such aberrations as a simpler alternative to experimental methods. Such modeling normally assumes the ground to be fully conducting. A method is presented for considering imperfect terrain conductivity within the framework of the uniform theory of diffraction (UTD). First, a single impedance wedge formulation is developed to a form that resembles the standard form of UTD, with only one extra term in the diffraction coefficient. This extends the applicability of the standard UTD formulation and software packages to the case of the imperfectly conducting terrain. The method has been applied to a real airport site in India and improved agreement with measured glidescope parameters is demonstrated.

#### A88-39375 NAVIGATION BY SATELLITE - THE NEXT STEP FOR CIVIL **AVIATION**

GENEVIEVE EYDALEINE (CNES, Paris, France) (ISSN 0018-8778), vol. 43, March 1988, p. 16-18.

The development of a global satellite navigation system is discussed. The GPS-Navstar system has the advantage of 100 m accuracy, but has discontinuities in service and has a relatively slow surveillance system. The RTCA has concluded that for GPS to be approved for civil use, three supplementary satellites would have to be launched into geostationary orbits, bringing the number of satellites used by GPS to 24. This increase would almost totally solve the problem of continuity of service and would enable the receiver to judge by itself the validity of information received by the six satellites in its sight. It would also make receivers much more complicated and would not solve the problem of cases where one or more satellites are not available.

#### A88-39813#

#### MEASUREMENT OF MULTIPATH PROPAGATION OF **ELECTROMAGNETIC WAVES IN ACTUAL AIRPORT** ENVIRONMENTS [MESSUNG DER MEHRWEGEAUSBREITUNG ELEKTROMAGNETISCHER WELLEN IN REALEN FLUGHAFENUMGEBUNGEN]

KLAUS-G. WESTPHAL (Braunschweig, Technische Universitaet, (URSI and Brunswick, Federal Republic of Germany) Nachrichtentechnische Gesellschaft, Gemeinsame Tagung, Kleinheubach, Federal Republic of Germany, Oct. 5-9, 1987) Kleinheubacher Berichte (ISSN 0343-5725), vol. 31, 1988, p. 517-526. In German.

The measurement of multipath propagation of electromagnetic waves during airport approach is described. A Doppler measurement apparatus is used which permits propagation in the VHF, L, and C frequency bands to be evaluated. Various methods of representing the measurement results are shown, and a concrete example is presented in which individual reflector types are distinguished from each other and described.

#### A88-40519

#### IMPLEMENTATION OF AERONAUTICAL MOBILE SATELLITE SERVICES (AMSSS) [LA MISE EN PLACE DES COMMUNICATIONS MOBILES AERONAUTIQUES PAR SATELLITES /AMSS/]

OLIVIER CAREL (Direction de la Navigation Aerienne, Service (Instituts de Navigation, Congres Technique, Paris, France) International, Sydney, Australia, Feb. 2-5, 1988) Navigation (Paris) (ISSN 0028-1530), vol. 36, April 1988, p. 208-215. In French.

Civil aviation systems for voice and data transmission such as VHF, HF, and ACARS/AIRCOM are reviewed, and current mobile systems are discussed. The IOAC future air navigation systems committee analysis of aeronautical mobile satellite systems indicates that VHF and secondary surveillance radar will continue to be used in the future, that HF will probably be discontinued, and that passenger telephone services using either satellite or cellular techniques will be developed. The increased use of coded data flow for technical applications is also predicted.

#### A88-40533#

#### CURRENT TREND OF DIGITAL MAP PROCESSING

Japan Society for NOBUO EBATO and SHIGERU KIMURA Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 36, no. 408, 1988, p. 26-29. In Japanese. refs

#### A88-41089

#### AIRBORNE DATA BASES - A QUIET REVOLUTION

JAMES E. TERPSTRA (Jeppesen Sanderson, Inc., Englewood, CO) Journal of Navigation (ISSN 0373-4633), vol. 41, May 1988,

An overview of the use of the data base at Jeppesen Sanderson is given, stressing the NavData system and its core, the Flight Information Master Data Base. The discussion includes data base input and output, data edit checks, data base applications and plans for the future. On-board navigation computers using electronic navigation information are being implemented to relieve pilot workload and reduce error. The NavData services are also being applied to flight simulation.

#### National Aeronautics and Space Administration. N88-22883\*# Hugh L. Dryden Flight Research Center, Edwards, Calif. DEVELOPMENT OF A MOBILE RESEARCH FLIGHT TEST SUPPORT CAPABILITY

DONALD C. RHEA and ARCHIE L. MOORE May 1988 12 p Presented at the 4th Flight Test Conference, San Diego, Calif., 18-20 May 1988

(NASA-TM-100428; H-1456; NAS 1.15:100428; AIAA-88-2087) Avail: NTIS HC A03/MF A01 CSCL 14B

This paper presents the approach taken by the NASA Western Aeronautical Test Range (WATR) of the Ames Research Center to develop and utilize mobile systems to satisfy unique real-time research flight test requirements of research projects such as the advanced fighter technology integration (AFTI)F-16, YAV-8B Harrier, F-18 high-alpha research vehicle (HARV), XV-15, and the UH-60 Black Hawk. The approach taken is cost-effective, staff efficient, technologically current, and provides a safe and effective research flight test environment to support a highly complex set of real-time requirements including the areas of tracking and data acquisition, communications (audio and video) and real-time processing and display, postmission processing, and command uplink. The development of this capability has been in response to the need for rapid deployment at varied site locations with full real-time computations and display capability. This paper will discuss the requirements, implementation and growth plan for mobile systems development within the NASA Western Aeronautical Test Range. **Author** 

N88-22884\*# Kansas Univ. Center for Research, Inc., Lawrence. Flight Research Lab.

#### ANALYSIS OF A RANGE ESTIMATOR WHICH USES MLS **ANGLE MEASUREMENTS Final Report**

DAVID R. DOWNING and DENNIS LINSE Jul. 1987 81 p (Contract NAG1-490)

(NASA-CR-182896; NAS 1.26:182896; KU-FRL-671-1) Avail:

NTIS HC A05/MF A01 CSCL 17G

A concept that uses the azimuth signal from a microwave landing system (MLS) combined with onboard airspeed and heading data to estimate the horizontal range to the runway threshold is investigated. The absolute range error is evaluated for trajectories typical of General Aviation (GA) and commercial airline operations (CAO). These include constant intercept angles for GA and CAO. and complex curved trajectories for CAO. It is found that range errors of 4000 to 6000 feet at the entry of MLS coverage which then reduce to 1000-foot errors at runway centerline intercept are possible for GA operations. For CAO, errors at entry into MLS coverage of 2000 feet which reduce to 300 feet at runway centerline interception are possible. Author

#### N88-22886\*# Alphatech, Inc., Burlington, Mass. EXPANDED ENVELOPE CONCEPTS FOR AIRCRAFT CONTROL-ELEMENT FAILURE DETECTION AND **IDENTIFICATION Final Report**

JEROLD L. WEISS and JOHN Y. HSU Jun. 1988 100 p (Contract NAS1-18004)

(NASA-CR-181664; NAS 1.26:181664; TR-378) Avail: NTIS HC

A05/MF A01 CSCL 17G

The purpose of this effort was to develop and demonstrate concepts for expanding the envelope of failure detection and isolation (FDI) algorithms for aircraft-path failures. An algorithm which uses analytic-redundancy in the form of aerodynamic force and moment balance equations was used. Because aircraft-path FDI uses analytical models, there is a tradeoff between accuracy and the ability to detect and isolate failures. For single flight condition operation, design and analysis methods are developed to deal with this robustness problem. When the departure from the single flight condition is significant, algorithm adaptation is necessary. Adaptation requirements for the residual generation portion of the FDI algorithm are interpreted as the need for accurate, large-motion aero-models, over a broad range of velocity and altitude conditions. For the decision-making part of the algorithm, adaptation may require modifications to filtering operations, thresholds, and projection vectors that define the various hypothesis tests performed in the decision mechanism. Methods of obtaining and evaluating adequate residual generation and decision-making designs have been developed. The application of the residual generation ideas to a high-performance fighter is demonstrated by developing adaptive residuals for the AFTI-F-16 and simulating their behavior under a variety of maneuvers using the results of a NASA F-16 simulation. Author

05

#### **AIRCRAFT DESIGN, TESTING AND PERFORMANCE**

Includes aircraft simulation technology.

#### A88-37183

#### THE HIGH TECHNOLOGY TEST BED PROGRAM - AN **OVERVIEW**

H. W. COPELAND, JR. and S. K. HOFFMANN (Lockheed-Georgia IN: International Powered Lift Conference and Co., Marietta) Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 101-103.

(SAE PAPER 872312)

Tactical Airlifters in the battlefield of the future will be required to operate on unprepared or damaged runways in all weather conditions without navigational or landing aids. Lockheed is addressing technologies required for these missions in an independent research and development program using a highly modified commercial C-130 aircraft as the technology integration focal point - a 'Flying Laboratory'. The HTTB Program addresses the major technology areas of advanced short takeoff and landing, survivability, advanced cockpit, and electronic systems. The Program goal is to develop systems to support autonomous operations into a 1500-foot landing area, up to and including a 50-foot obstacle at the runway threshold.

A88-37184 De Havilland Aircraft Co. of Canada Ltd., Downsview (Ontario).

#### A REVIEW OF THE DE HAVILLAND AUGMENTOR-WING POWERED-LIFT CONCEPT AND ITS FUTURE APPLICATIONS

J. E. FARBRIDGE (de Havilland Aircraft Company of Canada, IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 105-116. Research supported by the Canadian Department of Industry, Trade and Commerce, DND, and NASA, refs. (SAE PAPER 872313)

A development history is presented for the augmentor wing powered-lift concept from the mid-1960s to the present. The augmentor wing concept employs a thick, compound or multielement airfoil wing section. Thickness/chord is up to 24 percent, and coefficient of lift above 0.6 for cruise Mach numbers of the order of 0.7. Transport aircraft incorporating these technologies can achieve ultrashort takeoff and landing capabilities on the basis of no more thrust than that installed for cruise.

O.C.

#### PERFORMANCE FLIGHT TESTING OF A SINGLE ENGINE POWERED LIFT AIRCRAFT

RALPH D. KIMBERLIN (Tennessee, University, Tullahoma) International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 117-137. (SAE PAPER 872314)

This paper describes a low cost flight test program and presents the results for evaluating the performance of the Ball-Bartoe JETWING upper surface blown powered lift aircraft with and without the thrust augmenting ejector installed. The program included a ground test series for thrust calibration by dynamometer and by measuring the velocity profile with laser velocimeter followed by performance flight testing to obtain lift coefficient vs. angle of attack and lift coefficient vs. excess thrust coefficient. Stability and handling characteristics were also evaluated. Flight test results when compared with wind tunnel data generally showed good agreement although the lift curve slope obtained by flight test is somewhat less than that from wind tunnel primary testing because

of inaccuracies involved in measuring angle of attack in flight.

Author

A88-37186\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

QUIET SHORT-HAUL RESEARCH AIRCRAFT - A SUMMARY OF FLIGHT RESEARCH SINCE 1981

DENNIS W. RIDDLE, VICTOR C. STEVENS, and JOSEPH C. EPPEL (NASA, Ames Research Center, Moffett Field, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 139-163. refs (SAE PAPER 872315)

The Quiet Short-Haul Research Aircraft (QSRA), designed for flight investigation into powered-lift terminal area operations, first flew in 1978 and has flown 600 hours since. This report summarizes QSRA research since 1981. Numerous aerodynamic flight experiments have been conducted including research with an advanced concept stability and control augmentation and pilot display system for category III instrument landings. An electromechanical actuator system was flown to assess performance and reliability. A second ground-based test was conducted to further evaluate circulation-control-wing/upper-surface-blowing performance. QSRA technology has been transferred through reports, guest pilot evaluations and airshow participation. QSRA future research thoughts and an extensive report bibliography are also presented.

**A88-37187\*** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

FLIGHT EVALUATION OF AN INTEGRATED CONTROL AND DISPLAY SYSTEM FOR HIGH-PRECISION MANUAL LANDING FLARE OF POWERED-LIFT STOL AIRCRAFT

CHARLES S. HYNES, GORDON H. HARDY (NASA, Ames Research Center, Moffett Field, CA), and THOMAS J. KAISERSATT IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 165-180. refs

(SAE PAPER 872316)

An account is given of the features and performance of a manual landing flare and touchdown system capable of great precision, as demonstrated by its installation in the NASA Quiet Short-haul Research Aircraft (QSRA). The integrated cockpit display and closed-loop control employed constitutes a trajectory-augmentation system that extends QSRA flight control from augmentation of altitude, flight path angle, and airspeed, to the augmentation of the trajectory itself. The + or - 18 ft touchdown dispersion achieved is approximately equal to that obtained during aircraft carrier trials of the same aircraft.

#### A88-37188

### SOME TOPICS OF ASKA'S FLIGHT TEST RESULTS AND ITS FUTURE PLAN

TOSHIO BANDO, YOSHIO HAYASHI (National Aerospace Laboratory, Chofu, Japan), OSAMU KOBAYASHI, and ISAO KAGEYAMA (Kawasaki Heavy Industries, Ltd., Kobe, Japan) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 181-187. refs (SAE PAPER 872317)

The quiet STOL research airplane ('ASKA') was developed as a research aircraft that would provide high levels of STOL performance at low levels of community noise. The ASKA is a C-1 tactical transport, modified to incorporate an Upper Surface Blowing (USB) type propulsive-lift system. Attention is given to the major subjects in evaluation of a newly developed engine, the actual proof of the structure, confirmation of different avionics systems, and documenting of fundamental flying quality and performance.

#### A88-37189

#### V/STOL AND THE ROYAL AIR FORCE

G. C. WILLIAMS (Ministry of Defence, London, England) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 189-193. (SAE PAPER 872319)

THE ROYAL AIR FORCE was the first military organization to deploy a fixed-wing vertical/short take-off and landing aircraft - the British Aerospace Harrier. This paper describes the Royal Air Force's concept of operations for its current force of Harrier GR3s and sets out the advantages of the new Harrier GR5. Finally, it discusses the future of V/STOL with particular regard to Royal Air Force interest in the proposed Advanced Short Take-Off and Vertical Landing aircraft.

#### A88-37190

#### NEAR TERM ENHANCEMENTS OF THE AV-8B HARRIER II

ROGER H. MATHEWS (McDonnell Douglas Corp., Saint Louis, MO) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 195-200. (SAE PAPER 872321)

Major upgrade items of the AV-8B Harrier II, a powered lift V/STOL, are considered, and the development of a radar equipped Harrier II is discussed. A digital engine control system has been designed and tested which requires fewer maintenance man hours per operating hour and provides reduced life cycle cost. The night attack suite consists of a navigation FLIR, a digital moving map, a wide field-of-view HUD, night vision goggle (NVG) compatible lighting, and 'cat's eyes' NVGs. Objectives of the new F402-RR-408 engine are to double the time before overhaul to 1000 hours, improve maintainability through modular construction, and increase thrust at elevated ambient temperatures.

#### A88-37202 PROPULSION/AERODYNAMIC INTEGRATION IN ASTOVL COMBAT AIRCRAFT

GEORGE M. APPLEYARD (British Aerospace, PLC, Military Aircraft Div., Brough, England) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 337-348. Research supported by the Ministry of Defence Procurement Executive. refs (SAE PAPER 872333)

The provision of STOVL capability and a Supersonic capability in a small combat aircraft simultaneously introduces design and operational penalties, freedoms and complexities. The respective minimization, exploitation, and simplification of these represents a unique challenge, which must be met in order to maximize overall cost-effectiveness. The key to this lies in the full exploitation of the potential for powerplant/airframe integration of the advanced STOVL aircraft, via the Integrated Flight/Powerplant Control System (IFPCS). The overall design philosophy and control strategies of the IFPCS are highlighted and discussed with particular reference to the single-engined vectoring nozzle aircraft. These include: (1) controlling the combination of propulsive thrust vector and aerodynamic force vector to achieve optimum aircraft response and optimum aircraft performance; (2) controlling the manner in which the powerplant generates the required thrust vector in order to achieve maximum powerplant performance consistent with safe and reliable engine operation.

#### A88-37204

### THE APPLICATION OF CIRCULATION CONTROL PNEUMATIC TECHNOLOGY TO POWERED-LIFT STOL AIRCRAFT

ROBERT J. ENGLAR (Lockheed Aeronautical Systems Co., Marietta, GA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 357-369. refs

(SAE PAPER 872335)

The flow-entraining capability of the Circulation Control Wing

blown high-lift system has been synergistically combined with upper-surface-mounted engines to provide an even stronger STOL potential. The resulting configurations generate very supercirculation lift plus vertical а component pneumatically-deflected engine thrust. Small-scale wind-tunnel and full-scale static thrust-deflection tests have verified these concepts by confirming thrust deflections of greater than 90 deg produced pneumatically by nonmoving aerodynamic surfaces. High lift can be maintained while interchanging thrust recovery and thrust offset for optimum STOL performance, as well as for simplified heavy-lift or overload capability.

#### A88-37218

# RESULTS OF A PRECISION HOVER SIMULATION ON THE ONE-TO-ONE MOTION LARGE AMPLITUDE RESEARCH SIMULATOR

MARSHALL S. HYNES (U.S. Navy, Naval Air Development Center, Warminster, PA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 519-530. refs (SAE PAPER 872356)

A piloted simulation was conducted to: evaluate attitude response bandwidth as a predictor of V/STOL hover flying qualities. validate a unique convolution integral simulation technique (CONVO), and qualitatively assess the one-to-one motion characteristics of the Grumman Large Amplitude Research Simulator (LARS). Handling qualities ratings demonstrated good correlation with attitude response bandwidth for both attitude command and rate command response types, however, a minimum damping requirement is necessary to supplement the bandwidth requirement for attitude command responses. Formal validation of the CONVO technique was not possible due to inaccurate modeling of the Grumman V/STOL Design 698, however, CONVO fidelity for the bandwidth investigation was satisfactory. Comparisons of pilot evaluations of the Design 698 on LARS and the NASA Ames VMS show LARS evaluations to be much worse due to high controller sensitivity. Author

#### A88-37223

### SPECIAL REPORT ON BELL ACAP FULL-SCALE AIRCRAFT CRASH TEST

JAMES D. CRONKHITE (Bell Helicopter Textron, Fort Worth, TX) and L. T. MAZZA (U.S. Army, Aviation Applied Technology Directorate, Fort Eustis, VA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 575-587. refs (SAE PAPER 872362)

The results of a full-scale aircraft crash test of the Bell ACAP vehicle, conducted on August 27, 1987, are examined. The Bell ACAP was developed under a research program aimed specifically at demonstrating the technology advancement offered by composite materials when used in both primary and secondary airframe structures. Test results demonstrated that the aircraft successfully met the U.S. Army's stringent crash survivability requirements of 50-ft/s resultant ground impact velocity at an aircraft attitude of 10-deg roll and 10-deg nose-up pitch without any apparent serious injuries to the occupants. Namely, the overhead transmission mass was retained, the protective shell structure was maintained, the controlled seat stroking remained within limits at all locations, and the fuel was contained. Comparisons of test results with the KRASH computer simulation showed good agreement.

#### A88-37224

#### **TECHNOLOGY FOR ADVANCED HELICOPTERS**

W. EUAN HOOPER (Boeing Helicopter Co., Philadelphia, PA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 589-596. refs (SAE PAPER 872370)

The recent history of helicopter technology is recalled, and

the current status and future trends are surveyed and illustrated with extensive drawings and diagrams. The analysis and recommendations of a 1961 review (Harris, 1961) are briefly summarized and contrasted with the present emphases on vibration, noise, and R&M factors. Particular attention is given to the application of advanced CFM to increase speed, reduce vibration (via improved modeling of rotor loading and optimization of aerodynamics and structures), and avoid noise due to blade-vortex interaction and shock delocalization. Also discussed are the improved efficiency and reliability obtained by using advanced composite materials, efforts to produce propulsion systems with lower fuel consumption and higher thrust/weight ratios, and the performance of the Model 360 Advanced Technology Demonstrator helicopter.

#### A88-37229

### CONFIGURATION E-7 SUPERSONIC STOVL FIGHTER/ATTACK TECHNOLOGY PROGRAM

JOHN E. JENISTA and ARTHUR E. SHERIDAN (General Dynamics Corp., Fort Worth, TX) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 669-677.

(SAE PAPER 872379)

The program covering the design and early technology development of Configuration E-7, a supersonic STOVL Fighter/Attack aircraft is described. This aircraft uses the ejector principle to augment engine fan air for vertical lift. The initial design objectives selected in 1980 are listed and discussed. Some design considerations applicable to the propulsion concept and the chosen configuration are mentioned. The test program accomplished thus far, including wind tunnel models plus other test articles and activities is outlined. The program has proceeded without major technologicl obstacles and a full-scale engine-powered model will soon be ready for test.

#### A88-37230

### APPLYING VECTORED THRUST V/STOL EXPERIENCE IN SUPERSONIC DESIGNS

MICHAEL MANSELL (British Aerospace PLC, London, England) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 679-690. (SAE PAPER 872381)

Design features of a vectored thrust V/STOL aircraft are discussed, and the operational advantages of vectored thrust that should be considered in the design of supersonic V/STOL fighter aircraft are reviewed. Advantages of vectored thrust with plenum chamber burning (PCB) for combat are discussed which are related to the use of thrust vectoring in forward flight (increasing agility and maneuverability) and the exploitation of the sky-jump launch. A V/STOL ground effects facility to study environmental and aircraft problems related to the use of PCB to enhance vertical lift performance is also described.

#### A88-37231

#### A SUPERSONIC DESIGN WITH V/STOL CAPABILITY

P. W. LIDDELL (British Aerospace PLC, Military Aircraft Div., Preston, England) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 691-703.

(SAE PAPER 872382)

After presenting a development history for the P103 STOVL supersonic flight-capable military aircraft concept, attention is given to the results obtained to date by a comprehensive wind tunnel study of its near-ground aerodynamics. P103 is a two-RB 199 engine-based tilt-nacelle canard configuration. An account is given of P103's combat modeling and simulation results and hover-condition hot gas reingestion characteristics. The configuration is noted to exhibit low supersonic drag, good transonic characteristics, high maximum speed, and good STOVL controllability with the nacelles fully tilted.

#### A88-37232

#### THE F-15 STOL AND MANEUVER TECHNOLOGY DEMONSTRATOR (S/MTD) PROGRAM

FRANKLIN D. ROBERTS (McDonnell Douglas Corp., Saint Louis, MO) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 705-714. (Contract F33615-84-C-3015)

(SAE PAPER 872383)

The incorporation of four new technologies into modern fighter design is considered: (1) a two-dimensional vectoring/reversing nozzle; (2) integrated flight/propulsion control; (3) rough/soft field STOL landing gear; and (4) an advance pilot/vehicle interface. A program to study these technologies using a modified F-15 STOL aircraft is described. Fortran simulations were conducted to evaluate control laws and cockpit displays. Wind tunnel tests,

aircraft ground test, and projected flight tests are also discussed. The goal is to achieve operation from a 1500 x 50 foot runway.

A88-37234\* National Aeronautics and Space Administration.

Ames Research Center, Moffett Field, Calif.

USING FREQUENCY-DOMAIN METHODS TO IDENTIFY XV-15 AEROELASTIC MODES

C. W. ACREE, JR. (NASA, Ames Research Center, Moffett Field, CA) and MARK B. TISCHLER (U.S. Army, Aeroflightdynamics Directorate, Moffett Field, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 721-733. Previously announced in STAR as N88-17646. refs (SAE PAPER 872385)

The XV-15 Tilt-Rotor wing has six major aeroelastic modes that are close in frequency. To precisely excite individual modes during flight test, dual flaperon exciters with automatic frequency-sweep controls were installed. The resulting structural data were analyzed in the frequency domain (Fourier transformed) with cross spectral and transfer function methods. Modal frequencies and damping were determined by performing curve fits to transfer function magnitude and phase data and to cross spectral magnitude data. Results are given for the XV-15 with its original metal rotor blades. Frequency and damping values are also compared with earlier predictions.

#### A88-37703

### FLIGHT FATIGUE TESTING OF HELICOPTERS [LETNYE PROCHNOSTNYE ISPYTANIIA VERTOLETOV]

ROSTISLAV ALEKSANDRO MIKHEEV, VIKTOR SEMENOVICH LOSEV, and ALEKSANDR VLADIMIROV BUBNOV Moscow, Izdatel'stvo Mashinostroenie, 1987, 128 p. In Russian.

Methods for the flight fatigue testing of helicopters and the required metrological support are reviewed. In particular, attention is given to a systems approach to flight fatigue testing, characteristics of the fatigue loading of helicopter components, dynamic instability, and safety considerations during testing. The discussion also covers the airborne and ground-based components of the data processing and measurement system, measurements of the rotor forces and moments, loading of the chassis, fuselage, and stabilizer, and vibration testing and analysis.

#### A88-38352

#### ALMOST ALL COMPOSITE HELICOPTER

JAMES H. BRAHNEY Aerospace Engineering (ISSN 0736-2536), vol. 8, May 1988, p. 15-18.

The 'Model 360' helicopter, which is powered by two 4200-shp turboshaft engines, combines the extensive use of advanced composite materials with modularized assembly techniques to serve as a technology validation platform for next-generation rotorcraft technology. Advanced composites are employed not only in such typical structures as the rotor blades and hubs, and such attractive candidates for further application as the fuselage structure, but also the altogether novel main beams and retractable bellcranks

of the landing gear. The airframe consists of five major subsystem modules, including the tunnel, cockpit, fuselage, nose enclosure, and cabin floor/fuel-tank assembly.

O.C.

#### A88-38353

#### RADIAL TIRES FOR AIRCRAFT?

JAMES H. BRAHNEY Aerospace Engineering (ISSN 0736-2536), vol. 8, May 1988, p. 21-23.

Over the last several years, such military aircraft as the F-15E and F-16, as well as Airbus-family commercial aircraft, have been using radial rather than bias-ply tires; the primary structural difference between the two being that, in a radial tire, the casing is surrounded circumferentially with belts of textile cords. The radial design results in lower shear stresses, weight savings, a greater spring rate, lower polar moment of inertia, superior cornering behavior, lower load deflection, and greater antiskid mechanism compatibility.

#### A88-38696

#### NOTAR - THE TAIL THAT WAGS THE DOG

MARK LAMBERT Interavia (ISSN 0020-5168), vol. 43, April 1988, p. 311, 312, 315.

The 'no tail rotor', or NOTAR system of ducted fan air, replacing the conventional helicopter tail rotor, has been implemented in a prototype OH-6 helicopter, and is intended for production incorporation into MD-500 series civil helicopters. Directional power is very high; the turning inertia of the prototype was twice as great as that of the conventional OH-6, so that turns 'on the spot' could be flown with virtually constant pedal position. The NOTAR boom used is constructed of composites, although the Coanda effect generated by the boom can be retained with much rougher surfaces.

#### A88-38701

#### AIAA FLIGHT TEST CONFERENCE, 4TH, SAN DIEGO, CA, MAY 18-20, 1988, TECHNICAL PAPERS

Conference sponsored by AIAA. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, 563 p. For individual items see A88-38702 to A88-38763.

The present conference discusses NASA Ames-Dryden Flight Research Facility aircraft flight flutter testing, the Radarbet expert system-based multiple trajectory estimator, numerical filtering techniques for noise reduction in digital telemetry, 'skunk works' prototyping, the NASA Integrated Test Facility and its impact on flight research, a flight test approach to pilot workload assessment, AFTI/F-111 Mission Adaptive Wing flight research, the European Fighter Aircraft program, and a real-time aerodynamic analysis system for use in flight. Also discussed are stability flight test verification by modal separation, air-to-air combat development of the AH-64A Apache, a Space Shuttle crew escape tube study, a real-time flight performance analysis technique for the X-29A, a National Space Test Range, diagnostics design requirements for integrated avionics subsystems, maintainability as a design parameter, the tactical significance of helicopter aerobatics, and the development of a mobile flight test support facility.

A88-38702\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

#### AIŘCRAFT FLIGHT FLUTTER TESTING AT THE NASA AMES-DRYDEN FLIGHT RESEARCH FACILITY

MICHAEL W. KEHOE (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 1-14. refs (AIAA PAPER 88-2075)

Many parameter identification techniques have been used at the NASA Ames Research Center, Dryden Flight Research Facility at Edwards Air Force Base to determine the aeroelastic stability of new and modified research vehicles in flight. This paper presents a summary of each technique used with emphasis on fast Fourier transform methods. Experiences gained from application of these techniques to various flight test programs are discussed. Also presented are data-smoothing techniques used for test data

distorted by noise. Data are presented for various aircraft to demonstrate the accuracy of each parameter identification technique discussed.

Author

#### A88-38703#

### AUTOLAND TESTING - PUSHING THE (BOTTOM) EDGE OF THE ENVELOPE

F. PARLINI (Boeing Commercial Airplane Co., Seattle, WA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 15-20. refs (AIAA PAPER 88-2076)

Automatic landing of aircraft in poor visibility conditions, or 'autoland', involves an autopilot's capture of the localizer radio beam as the aircraft approaches a landing field; after one or more turning maneuvers, the aircraft is aligned with the landing field's centerline and initiates its 2.5-3.0 deg glideslope. An account is presently given of the test methods and instrumentation required for expansion and certification of autoland systems' operational envelope.

O.C.

#### A88-38704#

#### F-15E FLIGHT TEST PROGRAM OVERVIEW - MARCH 1988

J. L. ROBERTS (McDonnell Aircraft Co., Saint Louis, MO) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 21-27. (AIAA PAPER 88-2077)

The F-15E aircraft is the latest derivative of the successful McDonnell-Douglas F-15 fighter series. This dual role aircraft is designed for the deep interdiction, night, air-to-ground mission while retaining its superb air-to-air capability. This overview of the F-15E flight test program presents general results to date and the test program concept including customer and contractor roles and responsibilities. The flight test program has achieved over 200 flights and 400 flight hours in the initial 14 calendar months utilizing two test aircraft. The program has been conducted within a combined test force structure with both contractor and USAF aircrews. Currently, the specification compliance phase of Development Test and Evaluation (DT&E) is nearing completion. Follow-on customer DT&E and Operational Test and Evaluation (OT&E) are scheduled to begin in the summer of 1988. Author

#### A88-38709#

#### T-46A FINAL REPORT

WENDELL H. SHAWLER (National Test Pilot School, Mojave, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 65-71. (AIAA PAPER 88-2092)

The T-46 flight test program was terminated on March 13, 1987. In the final days the flutter envelope was expanded, the 80 percent loads tests both positive and negative were completed, the flight control system was finalized, most of the handling qualities test were completed and a significant part of the I.O.T.& E. (Initial Operational Test and Evaluation) was completed with the two test aircraft and the first production aircraft. A summary of the total program including the management philosophy and major decisions, significant test results along with major problems, and some rationale as to why some of the key events will be presented as part of this paper.

#### A88-38719#

### AFTI/F-111 MISSION ADAPTIVE WING FLIGHT RESEARCH PROGRAM

KENNETH L. BONNEMA (USAF, Flight Dynamics Laboratory, Wright-Patterson AFB, OH) and STEPHEN B. SMITH (USAF, Flight Test Center, Edwards AFB, OH) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 155-161. refs (AIAA PAPER 88-2118)

The concept of a smooth variable-camber wing promises a

significant improvement in performance by adapting its airfoil shape to each task required by the aircraft's mission. A joint USAF and NASA program was established to prove that significant performance improvements can be achieved with a practical wing system that varies its contour in flight as a function of pilot inputs, flight conditions, and structural loads. The flight-test program began in October 1985 and includes two phases: manual and AFCS operation. The manual-phase flight tests were completed in November 1986. After a downtime for integration and checkout of the AFCS the AFCS test phase began in August 1987.

#### A88-38721#

#### PROGRAM REVIEW OF EUROPEAN FIGHTER AIRCRAFT

FRANZ J. ENZINGER (Messerschmitt-Boelkow-Blohm GmbH, Manching, Federal Republic of Germany) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 171-176. (AIAA PAPER 88-2120)

The European Fighter Aircraft (EFA) is a four-nation program (FRG, Italy, Spain, and UK) in response to the European airstaff requirement. It will be optimized for the air-to-air role. The EFA is a single-seat, twin-engine, delta-wing aircraft with a foreplane, unstable, highly maneuverable design embodying latest technology. Design emphasis is also placed on operability, reliability, maintainability, and testability as well as low mass and low signature. The engine is a new development. The radar is optimized for air-to-air and will provide a large number of operating modes and reliable operation in a high-density ECM environment. The flight test program comprises a number of prototype aircraft shared among the participating companies. Advanced flight test instrumentation and analysis methods will be used for economical and cost-effective flight testing.

#### A88-38722#

### AQM-127A FULL SCALE ENGINEERING DEVELOPMENT FLIGHT TEST PROGRAM

NICHOLAS C. VANATTA and MICHAEL E. INDERHEES (Martin Marietta Corp., Electronics and Missiles Group, Orlando, FL) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 177-183. (AIAA PAPER 88-2121)

The AQM-127A supersonic low altitude target is being developed to simulate the low altitude, sea-skimming supersonic missile threat against U.S. Navy battle groups. The mission of the AQM-127A is to provide aerial target presentations to support test, evaluation, and training exercises for antiship missile defense systems. The AQM-127A contractor flight-test program elements include the range-integration tasks, ground tests, captive flight tests, and free flight tests conducted at the Pacific Missile Test Center. The paper presents the flight-test-structure requirements and an overview of the planned objectives. It discusses the major technical issues and problems experienced in each phase and presents a summary of the corrective action taken to preserve schedule while maintaining minimum risk.

#### A88-38727#

# DEVELOPMENT AND QUALIFICATION OF S-76B CATEGORY 'A' TAKEOFF PROCEDURE FEATURING VARIABLE CDP AND V2 SPEEDS

KARL W. SAAL and JEFFREY L. COLE (United Technologies Corp., Sikorsky Aircraft Div., West Palm Beach, FL) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 224-234. (AIAA PAPER 88-2127)

An account is given of the development and qualification of a Transport Category 'A' takeoff and landing procedure for the twin-engined S-76B helicopter, which furnishes the flexibility required to encourage helicopter operators to use the Rotorcraft Flight Manual zero-exposure time takeoff and landing procedures. The takeoff procedure involves a variable critical decision-point

(CDP) and safety speed (V2), where the rejected and continued takeoff distances are directly proportional to CDP and V2 speeds, respectively; the lower CDP and V2 speeds accordingly signify shorter field lengths. A reduced gross weight/single-engine power pilot training procedure is developed.

O.C.

A88-38728#

#### A REAL-TIME AERODYNAMIC ANALYSIS SYSTEM FOR USE IN FLIGHT

A. BERTELRUD (High Technology Corp., Hampton, VA), J. BOECK (PRC Kentron International, Hampton, VA), B. HEAPHY, and M. PARKS (Computer Sciences Corp., Hampton, VA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 235-241. refs (AIAA PAPER 88-2128)

This paper describes a real-time analysis system used to document fuselage aerodynamic flow properties on a Boeing 737-100. The system allows the monitoring of aircraft reference parameters as well as aerodynamic data in reduced form, i.e., also boundary layer integral parameters like momentum thickness and shape factors. It also allows control of the measurement system to optimize it for different tasks, and it permits modifications to the system as the test flight proceeds. The measurements include static pressure distributions and local skin friction as well as time-averaged and turbulent boundary layer data.

A88-38729#

### STABILITY FLIGHT TEST VERIFICATION BY MODAL SEPARATION

JAMES W. KELLY (Kelly Engineering, Los Angeles, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 242-249. (AIAA PAPER 88-2129)

This paper describes a method of conducting flight test to verify an aircraft stability requirements. These requirements are stated in various documents for civil and military aircraft. The requirements are for the stability of the aircraft, structures, control system and pilot. The requirements are stated in terms of the geometry of the Complex Plane. A method is presented where design analysis and flight test verification are done on the Complex Plane.

Author

#### A88-38730# SIMULATION IN SUPPORT OF FLIGHT TEST - IN RETROSPECT

ROBERT G. HOEY IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 250-254.

(AIAA PAPER 88-2130)

A history of the use of simulation in support of flight testing is presented, concentrating on the activities at Edwards AFB and the author's personal experience with research and rocket-powered vehicles. The early use of analog computers as real time simulators is discussed as well as the transition to hybrid, and eventually, all-digital simulations. Analytical test methods, which were biproducts of simulation development such as parameter identification and accident investigations, are mentioned. The evolution of pilot interfaces and displays is described as well as some observations regarding test pilots' acceptance of simulators in the test environment. Experience with inflight simulations and motion systems is touched on briefly. Future challenges such as the rapid validation and use of flight test data in training simulators, and availability of low cost, high quality visual displays are presented.

**A88-38731\***# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

FLIGHT TESTING A V/STOL AIRCRAFT TO IDENTIFY A FULL-ENVELOPE AERODYNAMIC MODEL

B. DAVID MCNALLY and RALPH E. BACH, JR. (NASA, Ames

Research Center, Moffett Field, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 255-267.

(AIAA PAPER 88-2134) Flight-test techniques are being used to generate a data base for identification of a full-envelope aerodynamic model of a V/STOL fighter aircraft, the YAV-8B Harrier. The flight envelope to be modeled includes hover, transition to conventionally flight and back to hover, STOL operation, and normal cruise. Standard V/STOL operation, and normal cruise. Standard V/STOL procedures such as vertical takeoff and landings, and short takeoff and landings are used to gather data in the powered-lift flight regime. Long (3-5-min) maneuvers which include a variety of input types are used to obtain large-amplitude control and response excitations. The aircraft is under continuous radar tracking; a laser tracker is used for V/STOL operations near the ground. Tracking data are used with state-estimation techniques to check data consistency and to derive unmeasured variables, for example, angular accelerations. A propulsion model of the YAV-8B's engine and reaction control system is used to isolate aerodynamic forces and moments for model identification. Representative V/STOL flight data are presented. The processing of a typical short-takeoff and slow-landing maneuver is illustrated.

A88-38735# FLIGHT TEST EXPERIENCE WITH AN RPV EMERGENCY (PARACHUTE) RECOVERY SYSTEM

K. E. FRENCH (Lockheed Missiles and Space Co., Huntsville, AL) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 299-306. (AIAA PAPER 88-2139)

This paper describes emergency (parachute) recovery system uses and benefits experienced during engineering development and operational flight tests of the U.S. Army Aquila Remotely Piloted Vehicle (RPV). Included are brief descriptions of the Aquila RPV, the parachute subsystem, and operation of the parachute subsystem. The flight test programs are summarized with respect to total number of flights, number of RPVs used, number of crashes, and number of parachute recoveries. Postcrash and postparachute recovery repair cost data are considered in an evaluation of the relative cost effectiveness of emergency parachute recovery. It is shown that incorporation of emergency parachute recovery in the Aquila RPV system has saved the cost of approximately 16 RPVs in 550 flight tests accomplished with a total of 28 RPVs.

A88-38736#

# THE USE OF A COMPUTER MODEL TO INVESTIGATE DESIGN COMPATIBILITY BETWEEN THE QF-4 AIRCRAFT AND THE AQM-127A

DAVID L. GOODSON and SCOTT A. BINEGAR (Martin Marietta Corp., Electronics and Missiles Group, Orlando, FL) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 307-311. (AIAA PAPER 88-2143)

An account is given of the design requirements for the electrical power interface between AQM-127A supersonic/low altitude target drones currently under development of the U.S. Navy and the QF-4 aircraft. Attention is given to the various power load profiles likely to be encountered, and to the design and use of the computer model predicting system performance under various load configurations. The design enhancements instituted in the power interface as a result of model predictions, and the final design configuration, are also discussed.

A88-38738\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

DEVELOPMENT OF A REAL-TIME AEROPERFORMANCE ANALYSIS TECHNIQUE FOR THE X-29A ADVANCED TECHNOLOGY DEMONSTRATOR

R. J. RAY, J. W. HICKS (NASA, Flight Research Center, Edwards,

CA), and R. I. ALEXANDER (Computing Devices Co., Ottawa, Canada) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 323-337. refs (AIAA PAPER 88-2145)

The X-29A advanced technology demonstrator has shown the practicality and advantages of the capability to compute and display, in real time, aeroperformance flight results. This capability includes the calculation of the in flight measured drag polar, lift curve, and aircraft specific excess power. From these elements, many other types of aeroperformance measurements can be computed and analyzed. The technique can be used to give an immediate postmaneuver assessment of data quality and maneuver technique, thus increasing the productivity of a flight program. A key element of this new method was the concurrent development of a real-time in flight net thrust algorithm, based on the simplified gross thrust method. This net thrust algorithm allows for the direct calculation of total aircraft drag.

#### A88-38748#

### IMPACT PRESSURE ERROR ON THE EC-18B SUBSONIC AIRCRAFT

E. G. HERNANDEZ and NORMA F. TAYLOR (USAF, Flight Test Engineering Directorate, Wright-Patterson AFB, OH) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 419-423. refs (AIAA PAPER 88-2177)

This paper presents analysis and test results of pitot-static calibration flights on the USAF EC-18B aircraft showing the development of a large impact pressure error at subsonic Mach numbers. Details include first indications of the problem, the post flight analysis performed to verify its existence, the hypothesis developed to explain the error and the methods used to confirm the hypothesis.

Author

#### A88-38749#

# STUDY OF POWERED-LIFT AIRCRAFT USING JUMP STRUTS M. A. GAMON (Lockheed Aeronautical Systems Co., Burbank, CA) IN: AIAA Flight Test Conference, 4th, Sep Biogra CA, Mari

CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 424-434. refs (AIAA PAPER 88-2179)

The paper presents the results of an analytical study to predict the reduction in takeoff distance that can be achieved with a jump nose gear on the NASA Quiet Short-Haul Research Aircraft (QSRA). The jump gear concept involves the release of stored energy into the landing gear, causing a rapid extension of the gear which imparts a vertical velocity to the airplane. The purpose of jump gears is to allow an earlier than normal takeoff rotation yielding a reduction in takeoff distance. Results are presented which show the degree of correlation during takeoff roll and liftoff between the analytical model and test results for the basic QSRA configuration. The takeoff distance reductions achievable with a nose jump gear on the QSRA are presented, for both compressed gas and pyrotechnic jump nose gear designs. Takeoff distance reductions on the order of 12 to 20 percent are achievable with a jump nose gear on the QSRA. Time-history responses for a typical jump nose gear takeoff are presented to illustrate the nature of the airplane dynamic response during a jump takeoff.

#### A88-38750#

### FLIGHT TEST OF THE JAPANESE USB STOL EXPERIMENTAL AIRCRAFT ASKA

HIROYUKI YAMATO, NORIAKI OKADA, and TOSHIO BANDO (National Aerospace Laboratory, Chofu, Japan) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 435-447. refs

(AIAA PAPER 88-2180)

This paper describes the development and the flight test of the Japanese Upper Surface Blowing (USB) STOL experimental aircraft 'ASKA' of the Japanese National Aerospace Laboratory. The ASKA is a conversion of the Kawasaki C-1 tactical transport with four newly developed FJR710/600S turbofan engines on the wing to achieve the USB high lift system, combined with Boundary Layer Control and Stability and Control Augmentation system. Various kinds of quantitative evaluation on the performance, handling qualities and others will be made in the flight test program. Not only the flight test chiefly for the low-speed region, but also the high speed performance study in the wind tunnel, along with the Computational Fluid Dynamics application, have been made simultaneously to generate the data base for the high-speed region of the USB aircraft.

**A88-38762\***# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

### TECHNIQUES USED IN THE F-14 VARIABLE-SWEEP TRANSITION FLIGHT EXPERIMENT

BIANCA TRUJILLO ANDERSON, ROBERT R. MEYER, JR., and HARRY R. CHILES (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 529-548. refs (AIAA PAPER 88-2110)

This paper discusses and evaluates the test measurement techniques used to determine the laminar-to-turbulent boundary-layer transition location in the F-14 variable-sweep transition flight experiment (VSTFE). The main objective of the VSTFE was to determine the effects of wing sweep on the laminar-to-turbulent transition location at conditions representative of transport aircraft. Four methods were used to determine the transition location: (1) a hot-film anemometer system, (2) two boundary-layer rakes, (3) surface pitot tubes, and (4) liquid crystals for flow visualization. Of the four methods, the hot-film anemometer system was the most reliable indicator of transition.

#### A88-38763#

### A SURVEY OF THE FLIGHT TESTING AND EVALUATION OF CF M56 SERIES TURBOFAN

MALUR R. SHIVARAM (Hindustan Aeronautics, Ltd., Directorate of Aeronautics, Bangalore, India) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 549-557. refs (AIAA PAPER 88-2078)

General Electric (USA) and SNECMA (France) joined together in 1974 for undertaking development of a ten ton class engine CFM56. This engine has got extensive application in various new aircraft as well as reengining of some of the old projects. The flight certification experience in clearance of this engine on various types of aircraft viz. YC-15, DC-8, Boeing 737-300, KC135R, Airbus A320/A340 etc. has left behind a unique experience which could stimulate flight test engineers and others with a purpose of making future programs more efficient, economic and complete. This experience has demonstrated the intended reduction in fuel burn rates, noise reduction, stall free operation, flame out problems and provided useful lessons for planning, acquisition and processing of flight test data. The final picture which emerges out of this review is a successful and very promising future class of engine that is revolutionary in nature. Author

#### A88-38800

# POWER SUPPLY FOR AN EASILY RECONFIGURABLE CONNECTORLESS PASSENGER-AIRCRAFT ENTERTAINMENT SYSTEM

ARTHUR W. KELLY and WILLIAM R. OWENS (Sundstrand Corp., Sundstrand Advanced Technology Group, Rockford, IL) IN: PESC '87 - Annual IEEE Power Electronics Specialists Conference, 18th, Blacksburg, VA, June 21-26, 1987, Record. New York, Institute of Electrical and Electronics Engineers, Inc., 1987, p. 650-659.

Passenger-aircraft entertainment systems have previously consisted of a single video program shown at the front of the cabin and multiple audio channels available in the armrest. A recently developed system would place small video entertainment systems at every seat for the use of each passenger. Wiring such

#### 05 AIRCRAFT DESIGN, TESTING AND PERFORMANCE

a system with multiple connectors would cause reliability and maintenance problems and hinder timely reconfiguration of the cabin. A prototype connectorless power supply that inductively couples power to the seats across an air gap, and allows placement of seats anywhere in the cabin is reported. Both electrical and magnetic models of the connectorless power supply are developed, and measurements on the power supply are discussed. The prototype design is shown to be a practical implementation that meets all design requirements.

#### A88-39277

#### V-22 OSPREY - CHANGING THE WAY MAN FLIES

JULIAN MOXON Flight International (ISSN 0015-3710), vol. 133, May 14, 1988, p. 22-30.

With a cruise speed of 275 kt and an unrefueled range of 2100 n.mi., the U.S. Marine Corps' Osprey tilt-rotor VTOL aircraft will be capable of swift, global self-deployment. VTOL maximum gross weight will be 47,000 lb; tilting the rotors forward for short takeoff (500 ft) increases gross weight to 60,500 lb. More than 70 percent of the V-22's 12,500 lb structure is built from composite materials, so that the fuselage is made almost entirely of carbon fiber-reinforced epoxy. Power will be supplied by two cross-shafted T406-AD-400 turboshaft engines of 6000 shp output each, incorporating full-authority digital electronic control. A cut-away drawing of design details is provided.

#### A88-39415#

#### **DORNIER 328 TAKING SHAPE**

REINHOLD BIRRENBACH and WOLFGANG SCHMIDT Dornier-Post (English Edition) (ISSN 0012-5563), no. 2, 1988, p. 7-9.

A design optimization status report is made for the twin-turboprop Do 328 30-seat regional commuter airliner. CFD methods have been used with vector-processing computers to refine such aerodynamic design details as main landing gear integration, rear fuselage shape, and horizontal tail unit geometry. Extensive tests have been made of pressurized structure cycling and damage tolerance behavior. Allowances have been made in cockpit design to permit future enlargements of the avionics suite. Parts production is scheduled to begin for the Do 328 in October, 1988. Engine selection is scheduled for June, 1988.

#### A88-39481#

#### ANALYSIS OF PERFORMANCE MEASUREMENT RESULTS OF PROPELLER AIRCRAFT. I - FLIGHT PERFORMANCE [ANALIZA WYNIKOW POMIAROW OSIAGOW SAMOLOTU SMIGLOWEGO. I - OSIAGI W LOCIE]

ANDRZEJ KARDYMOWICZ Technika Lotnicza i Astronautyczna (ISSN 0040-1145), vol. 43, Jan. 1988, p. 8-10. In Polish.

A method for analyzing aircraft performance data is described. This method makes it possible to obtain the complete aircraft performance characteristics as required by current aircraft design specifications. The aircraft climbing characteristics in steady flight are considered.

#### A88-39504

#### TUPOLEV BACKFIRE

Air International (ISSN 0306-5634), vol. 34, June 1988, p. 267-275.

An account is given of information gathered to date on the configurational features, propulsion system, armaments, and performance capabilities of the Tupolev Backfire-B and -C variants; the latter, constituting about half the present force of 320 aircraft, is distinguished by new inlets with horizontal compression surfaces and a greater cross-sectional area, which may indicate the fitting of a more powerful engine than the initially employed NK-144 twin-spool low-bypass/reheated turbofan. A radius of action of over 5500 km has been inferred for subsonic high-level missions. Primary armament is the AS-4 'Kitchen' air-to-surface missile, with a variety of nuclear and conventional warheads.

#### A88-40530#

STRUCTURE AND EQUIPMENTS OF THE T-2 CCV AIRCRAFT

ETSUROU SENTOU, HIDETOSHI HIRATA, HIROSHI HAYAFUJI, NOBORU HATEMATA, TOSHIJI OHASHI et al. Japan Society for Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 35, no. 405, 1987, p. 500-510. In Japanese.

#### A88-40575#

ANALYSIS OF PERFORMANCE MEASUREMENT RESULTS OF AIRCRAFT. II - FLIGHT PERFORMANCE (ANALIZA WYNIKOW POMIAROW OSIAGOW SAMOLOTU SMIGLOWEGO. II -OSIAGI W LOCIE)

ANDRZEJ KARDYMOWICZ Technika Lotnicza i Astronautyczna (ISSN 0040-1145), vol. 43, Feb. 1988, p. 8-10. In Polish. refs

#### A88-40704#

### FLOWFIELD STUDY AT THE PROPELLER DISKS OF A TWIN PUSHER. CANARD AIRCRAFT

NEAL J. PFEIFFER (Beech Aircraft Corp., Wichita, KS) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 19-26. refs (AIAA PAPER 88-2511)

A developmental study was undertaken to determine the inflow for a pusher propeller installation. The effects of wing trailing edge shape and nacelle orientation were evaluated for the Beech Starship. Potential flow computer analysis was used initially to examine the problem. This analysis showed that there is a possibility of highly non-uniform flow fields occurring near pusher propellers. Potential flow analysis does not give the complete picture, however, since it neglects the effects of viscosity. These viscous effects are significant when wing and canard wakes and fuselage and nacelle boundary layers pass through or near to a propeller disk. Wind tunnel testing using a five hole pressure probe was done to map the flow field velocity at the disk location to determine the viscous effects. The experimental velocities were resolved into propeller blade fitted coordinates in order to study the periodic variation of the flow past a blade as it rotates around the disk.

Author

# A88-40711\*# Vigyan Research Associates, Inc., Hampton, Va. AN ANALYTICAL METHOD FOR THE DITCHING ANALYSIS OF AN AIRBORNE VEHICLE

FARHAD GHAFFARI (Vigyan Research Associates, Inc., Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 98-109. Previously announced in STAR as N88-14968. refs (Contract NAS1-17919) (AIAA PAPER 88-2521)

A simple analytical method has been introduced for aerohydrodynamic load analysis of an airborne configuration during water ditching. The method employs an aerodynamic panel code, based on linear potential flow theory, to simulate the flow of air and water around an aircraft configuration. The free surface separating the air and water region is represented by doublet sheet singularities. Although all the theoretical load distributions are computed for air, provisions are made to correct the pressure coefficients obtained on the configuration wetted surfaces to account for the water density. As an analytical tool, the Vortex Separation Aerodynamic (VSAERO) code is chosen to carry out the present investigation. After assessing the validity of the method, its first application is to analyze the water ditching of the Space Shuttle configuration at a 12 degree attitude.

#### A88-40868#

### ANALYTICAL EVALUATION OF BIRDSTRIKE AGAINST A F-16A LAMINATED CANOPY

RICHARD A. SMITH and ROBERT E. MCCARTY (USAF, Flight Dynamics Laboratory, Wright-Patterson AFB, OH) AIAA, ASME, ASCE, and AHS, Structures, Structural Dynamics and Materials Conference, 29th, Williamsburg, VA, Apr. 18-20, 1988. 11 p. refs (AIAA PAPER 88-2268)

Computer simulations of bird impacts were carried out for four target locations along the F-16A aircraft canopy centerline. These

simulations were followed by birdstrike testing at the weakest point on the canopy as determined from the first four analyses. A simulation program called MAGNA (materially and geometrically nonlinear analysis) was used. MAGNA was used to prepare finite element models of the F-16A laminated canopy and to perform eigenvalue and nonlinear dynamic analyses. The capabilities of MAGNA are described in detail. It is found that birdstrike protection increases the farther aft along the canopy centerline that impact occurs, and that canopy/HUD impingement should not cause canopy failure.

#### THE USE OF SMOOTH BENDING MOMENT MODES IN HELICOPTER ROTOR BLADE VIBRATION STUDIES

G. T. S. DONE and M. H. PATEL (City University, London, England) Journal of Sound and Vibration (ISSN 0022-460X), vol. 123, May 22, 1988, p. 71-80. refs

Difficulties in the use of prescribed deflection modes for analyzing helicopter rotor blade vibration are overcome by the adoption of a special type of assumed mode. The case of flapping and lagging motions of the rotor blade is considered. The bending moment distributions of these assumed modes are those of the normal modes of a uniform cantilever beam, and they are smoothly varying, as actually occurs on the rotor blade. Natural frequencies and normal mode shapes for a rotating helicopter rotor blade which have been evaluated using these assumed modes compare well with previous results and with those obtained using a mathematical model.

#### A88-41250

#### X-31 - THROUGH THE GRAPE BARRIER

BILL SWEETMAN Interavia (ISSN 0020-5168), vol. 43, May 1988, p. 475, 476.

The X-31 research aircraft, of which two are under construction by U.S and West German manufacturers under the sponsorship of DARPA, the West German Ministry of Defense and the U.S. Navy, is a small, single-engine delta wing/canard configuration. The most distinctive and consequential feature of the design is a set of three thrust-vectoring paddles arrayed around the exhaust of the F404 engine, furnishing all-axis thrust deflections for dynamic maneuverability in high-alpha, low speed conditions. The development and testing of efficient, reliable control laws integrating the aerodynamic control surfaces with paddle thrust vectoring is a major concern of the X-31 program.

#### A88-41364

#### SUPPRESSING DISPLAY COCKPIT REFLECTIONS

RUDOLF HARTMANN (Martin Marietta Corp., Orlando, FL) Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1987, p. 45-50. refs

A 'heads-out-display' on a CRT screen may distract the crew members with whom a cockpit is shared if its light is reflected from a given crew station toward others by canopy panels, especially at night. Attention is presently given to a canopy reflection suppression system for the U.S. Army's Apache attack helicopter, which involved the placing of a linear polarizer over the CRT with its axis crossed relative to the 'skipping vector' of the reflection. This allowed the canopy panel to act as an analyzer, and resulted in a reduction of reflected luminance by a factor of

N88-22022# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.

#### MODEL SELECTION FOR THE MULTIPLE MODEL ADAPTIVE ALGORITHM FOR IN-FLIGHT SIMULATION M.S. Thesis

JAMES R. MATHES, JR. Dec. 1987 241 p (AD-A189715; AFIT/GE/ENG/87D-40) Avail: NTIS HC A11/MF A01 CSCL 01A

This thesis extends the research accomplished by Capt Pineiro and Lt Berens in the area of adaptive algorithm implementation. Specifically, this thesis explores the performance characteristics of the multiple model estimation algorithm and how they influence

the selection of aircraft models to allow the parameter adaptive control system to maintain tracking performance over a portion of the flight envelope. The aircraft dynamic equations used are those of the AFTI/F-16 and the control law design is based on the method developed by Professor Porter. After selecting a set of aircraft models that results in the best overall system response, the effect of adjusting the control law gains on the performance of the multiple model estimation algorithm is evaluated. By assuming that all states are accessible, sensor noise is then added to each of the longitudinal states to study how noise impacts model selection. A set of models that produces acceptable tracking performance over the desired flight envelope and the most immunity to sensor noise is then selected.

#### N88-22023# Naval Postgraduate School, Monterey, Calif. THE EFFECTS OF TORQUE RESPONSE AND TIME DELAY ON ROTORCRAFT VERTICAL AXIS HANDLING QUALITIES M.S. **Thesis**

PETER A. FYLES Dec. 1987 54 p

(AD-A189873) Avail: NTIS HC A04/MF A01 CSCL 01C

Research was conducted in support of updating the U.S. military handling qualities specification, MIL-H-8501A. The effects of torque response and time delay on rotorcraft vertical axis handling qualities were investigated with the use of a CH-47B variable stability helicopter and a fixed base simulator. The frequency response of displayed torque dynamics was found to be an important factor in vertical axis handling qualities. This finding has caused a revision to the update of the MIL-H-8501A.

N88-22024# Lockheed-California Co., Burbank.

KRASH PARAMETRIC SENSITIVITY STUDY: TRANSPORT CATEGORY AIRPLANES Final Report, Oct. 1985 - Jun. 1986 GIL WITTLIN and W. L. LABARGE Dec. 1987 169 p (Contract DTFA03-84-C-0004)

(AD-A189962; LR-31114; DOT/FAA/CT-87/13) Avail: NTIS HC A08/MF A01 CSCL 01C

The FAA/NASA jointly sponsored Controlled Impact Demonstration (CID) test was conducted. The CID test was a major milestone in a series of inter-related analyses and test prescribed in the FAA Crash Dynamics program. Prior to the CID test, several section and impact tests including analyses were performed. Subsequent to the CID test, correlation between KRASH pretest analyses and actual test data was evaluated. The actual CID test resulted in an unsymmetrical impact which was modeled and the results compared with the recorded test data. Analyses performed for air-to-ground, ground-to-ground, and longitudinal-only impacts. The results are presented in the form of triangular pulses with definition of the peak amplitude, base time duration and pulse change of velocity. The analytically obtained data are integrated with the full-scale aircraft and section test data to formulate crash design velocity envelopes. The results of the study are used to suggest seat dynamic test conditions.

GRA

N88-22025# Boeing Military Airplane Development, Seattle, Wash.

DEVELOPMENT AND EVALUATION OF AN AIRPLANE FUEL TANK ULLAGE COMPOSITION MODEL. VOLUME 2: EXPERIMENTAL DETERMINATION OF AIRPLANE FUEL TANK ULLAGE COMPOSITIONS Final Report, Nov. 1985 - Dec. 1986

A. J. ROTH Oct. 1987 118 p

(Contract F33615-84-C-2431)

(AD-A190408; D180-30344-2-VOL-2; AFWAL-TR-87-2060-VOL-2) Avail: NTIS HC A06/MF A01 CSCL 21D

The development and evaluation of a computer model designed to predict the composition of airplane fuel tank ullage spaces is documented in two volumes. Volume 1, Airplane Fuel Tank Ullage Computer Model: A detailed mathematical description of the model as it relates to the physical processes governing the ullage of an airplane fuel tank is included, along with user instructions and examples. Extensive comparisons of computer model predictions to experimental data are included. The model is interactive and can be used on a variety of computers including personal

computers. Volume 2, Experimental Determination of Airplane Fuel Tank Ullage Compositions: Experimental work conducted using a fuel tank simulator to investigate the composition of airplane fuel tank ullage spaces is described. The investigations include ullage mixing by diffusion and convection, oxygen evolution during simulated climbs and refueling and complete mission simulations.

N88-22029# Army Aviation Engineering Flight Activity, Edwards AFB, Calif.

PRELIMINARY AIRWORTHINESS EVALUATION OF THE UH-60A EQUIPPED WITH THE XM-139 VOLCANO MINE DISPENSING SYSTEM Final Report

THOMAS L. REYNOLDS, JOHN I. NAGATA, RANDALL W. CASON, and DAUMANTS BELTE Aug. 1987 125 p (AD-A190604) Avail: NTIS HC A06/MF A01 CSCL 15F

Preliminary airworthiness flight tests totalling 22.4 hr were conducted at West Palm Beach, Fla., (elevation 28 feet). The tests were conducted to determine handling qualities and performance of the UH-60A in the VOLCANO system configuration at an average mission gross weight of 20,500 pounds and a longitudinal center of gravity at fuselage station 351.0. The handling qualities of the UH-60A with the VOLCANO system installed were similar to the normal utility UH-60A. Three shortcomings were noted in this configuration: (1) the increased frequency and magnitude of tail shake with the VOLCANO installed; (2) the position error for the ship's airspeed system was increased by approximately 8 knots at higher speeds (120 KCAS) due to the installation of the VOLCANO mine dispensing system; and (3) Stability Augmentation System (SAS) OFF dynamic response, not attributed to the VOLCANO installation, was aperiodic and divergent. The UH-60A helicopter with VOLCANO failed to meet two requirements of the Prime Item Development Specification; however, noncompliances were not significant. Recommendations were made to incorporate data into the applicable portion of the VOLCANO operator's manual and to conduct additional testing.

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N88-22030# Army Aviation Engineering Flight Activity, Edwards AFB, Calif.

PRELIMINARY AIRWORTHINESS EVALUATION OF THE **UH-60A WITH ADVANCED DIGITAL OPTICAL CONTROL** SYSTEM (ADOCS) Final Report

GARY L. BENDER and ROBERT D. ROBBINS Aug. 1987 57 p

(AD-A190674) Avail: NTIS HC A04/MF A01 CSCL 01D

The (ADOCS) is being developed on a UH-60A helicopter by the Boeing Vertol Co. to demonstrate the feasibility of a digital optical control system. The U.S. Army Aviation Engineering Flight Activity conducted a Preliminary Airworthiness Evaluation of ADOCS installed on a UH-60A aircraft to evaluate the handling qualities and to provide data for issuance of an airworthiness release for a demonstration of the system to the Army aviation community through a guest pilot program. The ADOCS consists of a Primary Flight Control System, which incorporates limited-displacement side-arm controllers for pilot inputs (right-side pilot station only), and an Automatic Flight Control System (AFCS) which is used to augment the basic UH-60A stability. Displacement of the controllers is measured and transmitted optically to digital flight control processors where the control commands are summed with the AFCS commands and sent to the rotor control actuators. The evaluation was conducted at the BV Flight Test Center at Wilmington, Delaware between 25 March and 9 April, 1987 and consisted of 9 flights comprising 17.5 hours (14.9 productive hours). Tests included handling qualities, simulated system failures, and mission maneuvers. Three enhancing characteristics were found: (1) the ease in rolling to and maintaining a desired bank angle; (2) the capability to maintain hands-off stabilized hover with all selectable modes engaged, and; (3) the capability of the barometric altitude hold mode to maintain altitude during simulated instrument flight tasks. GRA

National Aeronautics and Space Administration. N88-22031\*# Langley Research Center, Hampton, Va.

SHAPE SENSITIVITY ANALYSIS OF WING STATIC **AEROELASTIC CHARACTERISTICS** 

JEAN-FRANCOIS M. BARTHELEMY and FRED D. BERGEN (Virginia Polytechnic Inst. and State Univ., Blacksburg.)

(NASA-TP-2808; L-16418; NAS 1.60:2808) Avail: NTIS HC A03/MF A01 CSCL 01C

A method is presented to calculate analytically the sensitivity derivatives of wing static aeroelastic characteristics with respect to wing shape parameters. The wing aerodynamic response under fixed total load is predicted with Weissinger's L-method; its structural response is obtained with Giles' equivalent plate method. The characteristics of interest include the spanwise distribution of lift, trim angle of attack, rolling and pitching moments, wind induced drag, as well as the divergence dynamic pressure. The shape parameters considered are the wing area, aspect ratio, taper ratio, sweep angle, and tip twist angle. Results of sensitivity studies indicate that: (1) approximations based on analytical sensitivity derivatives can be used over wide ranges of variations of the shape parameters considered, and (2) the analytical calculation of sensitivity derivatives is significantly less expensive than the conventional finite-difference alternative.

N88-22032# Aeronautical Research Inst. of Sweden, Stockholm. Structures Dept.

#### IN-SERVICE MEASUREMENTS OF SAAB SF-340 LANDING **GEAR LOADS**

ANDERS I. GUSTAVSSON Oct. 1987 106 p (Contract STU-84-4563)

(FFA-TN-1987-48; ETN-88-92199) Avail: NTIS HC A06/MF A01

Landing gear loads on a commuter airliner were continuously monitored for 6 months, including different load components, load cases, runway and weather conditions, and different pilots and ground personnel. The data are presented as cumulative excedances of longitudinal, transversal, and vertical loads obtained from the rainflow count analyses performed on-line during the measurements. It is emphasized that the nose gear is more severely strained in terms of ground reaction factors than the main gears.

N88-22033\*# National Aeronautics and Space Administration. Hugh L. Dryden Flight Research Center, Edwards, Calif.

EFFECTS OF UPDATE AND REFRESH RATES ON FLIGHT SIMULATION VISUAL DISPLAYS

GARY V. KELLOGG and CHARLES A. WAGNER May 1988 19 p

(NASA-TM-100415; H-1439; NAS 1.15:100415) Avail: NTIS HC A03/MF A01 CSCL 01C

An experiment was performed to study the effects of update and refresh rates on dynamic calligraphic CRT displays, particularly those used for visual displays in flight simulators. A moving horizontal line was generated on a CRT and observed at various velocities. Observations were made with both one and two refreshes per update. The data gathered from these observations are presented on plots of refresh-update rate as a function of display velocity. The display velocity where picture degradation occurs can be found by using these plots. These velocities are related to actual simulated aircraft angular and linear velocities. Results show that a visual display updated at 30 Hz and refreshed at 60 Hz degrades at very low simulated aircraft angular and linear velocities. These velocities at which degradation occurs can be significantly increased by increasing the update rate of the visual display. Only minor improvements are possible by refreshing the display twice for each uptake. To display rapidly changing flight scenery without degradation, the display update rate must be far in excess of 60 Hz, typically several hundred Hz.

N88-22245# Joint Publications Research Service, Arlington, Va. INFLUENCE OF UNSTEADY AERODYNAMIC FORCES ON DYNAMIC RESPONSE OF VARIABLE SWEEP AIRCRAFT **Abstract Only** 

MING YAN and CHUANREN QIU In its JPRS Report: Science and Technology. China p 62 11 Dec. 1987 Transl. into ENGLISH from Kongqidonglixue Xuebao (Mianyang, Peoples Republic of China), v. 5, no. 3, Sep. 1987 p 261-270 language document was announced in IAA as A88-14018 Avail: NTIS HC A06/MF A01

A numerical method to obtain a complete solution for the dynamic response of a variable sweep wing aircraft while changing the angle of sweep is presented. Both aerodynamic and trajectory computations are included. During the flight of the sweptback angle variation, the aerodynamic forces acting on the aircraft are obviously unsteady, therefore, methods for computing these forces and accompanying responses of aircraft are also presented.

Author

N88-22887# National Aerospace Lab., Amsterdam (Netherlands).

#### DEVELOPMENT OF A FLEXIBLE AND ECONOMIC HELICOPTER ENGINE MONITORING SYSTEM

A. A. TENHAVE and C. R. TJALSMA 23 Jul. 1986 16 p Presented at 12th the European Rotocraft Forum, Garmisch-Partenkirchen, Fed. Republic of Germany, 22-25 Sep.

(PB88-165147; NLR-MP-86046-U) Avail: NTIS HC A03/MF A01 CSCL 01C

In terms of fatigue life consumption the Royal Netherlands Navy (RNLN) is by now one of the leading operators of the Westland Lynx helicopter. Consequently, the RNLN feels a growing need to gain more insight into the Lynx fatigue loading environment. The topic of Lynx engine loading is the subject of a RNLN funded NLR research program aimed at investigating the possibility of continuous and automated monitoring of engine fatigue damage accumulation based on the Rolls-Royce Cyclic Lide Control concept. A pilot flight test program was performed, the results of which are being used for the development of a usable Lynx engine inflight data processor. Such a device will provide valuable information on the RLNL Lynx engine service loading and may be the basis of computerized Cyclic Life Control within the RNLN in the future. The major topics of the program are generally described.

NRR-22888# Technische Hogeschool, Delft (Netherlands). Faculty of Aerospace Engineering.

#### DESIGN STUDIES OF PRIMARY AIRCRAFT STRUCTURES IN **ARALL LAMINATES**

J. W. GUNNINK Jun. 1987 32 p Presented at the ICCM 6/ECCM 2 Meeting, London, United Kingdom, 20-24 Jul. 1987 (LR-520; B8733286; ETN-88-92463) Avail: NTIS HC A03/MF A01

Use of ARALL for fatigue dominated structural parts, like the lower wing and the pressure cabin of an aircraft, was assessed. To investigate the potential of the material, preliminary design studies were carried out on these components. The studies result in a weight reduction of more than 25 percent for the lower wing and the pressure cabin.

N88-22889# Technische Hogeschool, Delft (Netherlands). Faculty of Aerospace Engineering.

THE INITIAL CALCULATION OF RANGE AND MISSION FUEL **DURING CONCEPTUAL DESIGN** 

E. TORENBEEK Aug. 1987 27 p (LR-525; B8733276; ETN-88-92466) Avail: NTIS HC A03/MF Ã01

Derivations for the range of aircraft with gas turbine propulsion systems, which cannot be characterized to have either constant specific fuel consumption or constant propulsion efficiency are presented. The effects of different cruise techniques are investigated. It is found that for preliminary design purposes a very simple approximation of the fuel fraction can be used for all aircraft categories and various cruise techniques. This result was used to compute the total mission and reserve fuel. A method to derive the range parameter, eta L/D, for existing aircraft from their payload vs. range diagram is proposed. Such statistical data

of the range parameter may be used as input for the calculation of the fuel fraction. The method is intended for use during conceptual design studies for a first estimation of the takeoff weight.

#### N88-22890# European Space Agency, Paris (France). DIGITAL PROCESSING OF FLIGHT DATA OF A HELICOPTER WITHOUT USING ANTI-ALIASING FILTERS

RAINER HOLLAND (Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Brunswick, West Germany ) Mar. 1988 57 p Transl. into ENGLISH of Digitale Verarbeitung von Flugversuchsdaten ohne Verwendung von Anti-Aliasing-Filtern am Beispiel eines Hubschraubers (Brunswick, Fed. Republic of Germany, DFVLR), Jun. 1987 54 p Original language document was announced as N88-14981

(ESA-TT-1094; DFVLR-MITT-87-12; ETN-88-92562) Avail: NTIS HC A04/MF A01; original German version available from DFVLR. VB-PL-DO, 90 60 58, 5000 Cologne, Fed. Republic of Germany

The possibility of sampling helicopter flight test data directly without prior artificial band limiting was studied. Data are filtered in the digital computer, after sampling. The results are compared with the measurement data obtained from analog filters before sampling. The decisive advantage of digital filtering is apparent. This occurs as a program in a computer where the frequency characteristics can be rapidly changed by changing numerical values. Analog filters require an elaborate technical implementation and space for the mechanical construction. A smaller and more compact measuring system could be achieved if anti-aliasing filters are not used. The recording of unfiltered measurement values provides additional information on possible signal distortion. The frequency characteristics of the digital filter can be varied within defined limits (aliasing) after the flight test. The greater data quantity in the case of the unfiltered sampling is a disadvantage which, however, is no longer significant with the use of larger storage media. However, the high computing time can be a disadvantage if use under real-time conditions is necessary.

#### N88-22891\*# Van der Velden (Alexander J. M.), Berkeley, Calif. CONCEPTUAL FINAL PAPER ON THE PRELIMINARY DESIGN OF AN OBLIQUE FLYING WING SST Final Report

ALEXANDER J. M. VANDERVELDEN 6 Dec. 1987 (Contract NAG2-471)

(NASA-CR-182879; NAS 1,26:182879) Avail: NTIS HC A03/MF A01 CSCL 01C

A conceptual Oblique Flying Wing Supersonic Transport Aircraft (OFW, or surfplane because of its shape) was first proposed in 1957. It was reintroduced in 1987 in view of the emerging technology of artificial stabilization. This paper is based on the performance and economics study of an M2 B747-100B replacement aircraft. In order to make a fair comparison of this configuration with the B747, an end-sixties structural technology level is assumed. It is shown that a modern stability and control system can balance the aircraft and smooth out gusts, and that the OFW configuration equals or outperforms the B747 in speed, economy and comfort.

National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

#### MINIMUM WEIGHT DESIGN OF ROTORCRAFT BLADES WITH **MULTIPLE FREQUENCY AND STRESS CONSTRAINTS**

ADITI CHATTOPADHYAY (Analytical Services and Materials, Inc., Hampton, Va.) and JOANNE L. WALSH Mar. 1988 15 p Presented at the AIAA/ASME/ASCE/AHS 29th Structures, Structural Dynamics and Materials Conference, Williamsburg, Va., 18-20 Apr. 1988

(NASA-TM-100569; NAS 1.15:100569) Avail: NTIS HC A03/MF A01 CSCL 01C

Minimum weight designs of helicopter rotor blades with constraints on multiple coupled flap-lag natural frequencies are studied. Constraints are imposed on the minimum value of the blade autorotational inertia to ensure sufficient rotary inertia to autorotate in case of engine failure and on stresses to guard

against structural failure due to blade centrifugal forces. Design variables include blade taper ratio, dimensions of the box beam located inside the airfoil and magnitudes of nonstructural weights. The program CAMRAD is used for the blade modal analysis; the program CONMIN is used for the optimization. A linear approximation involving Taylor series expansion is used to reduce the analysis effort. The procedure contains a sensitivity analysis consisting of analytical derivatives for objective function and constraints on autorotational inertia and stresses. Central finite difference derivatives are used for frequency constraints. Optimal designs are obtained for both rectangular and tapered blades. Using this method, it is possible to design a rotor blade with reduced weight, when compared to a baseline blade, while satisfying all the imposed design requirements.

# N88-22893\*# General Dynamics Corp., Fort Worth, Tex. PARAMETRIC STUDY OF SUPERSONIC STOVL FLIGHT CHARACTERISTICS

DAVID C. RAPP Mar. 1985 245 p

(Contract NAS2-11753)

(NASA-CR-177330; NAS 1.26:177330) Avail: NTIS HC A11/MF

A01 CSCL 01C

A number of different control devices and techniques are evaluated to determine their suitability for increasing the short takeoff performance of a supersonic short-takeoff/vertical landing (STOVL) aircraft. Analysis was based on a rigid-body mathematical model of the General Dynamics E-7, a single engine configuration that utilizes ejectors and thrust deflection for propulsive lift. Alternatives investigated include increased static pitch, the addition of a close-coupled canard, use of boundary layer control to increase the takeoff lift coefficient, and the addition of a vectorable aft fan air nozzle. Other performance studies included the impact of individual E-7 features, the sensitivity to ejector performance, the effect of removing the afterburners, and a determination of optional takeoff and landing transition methods. The results pertain to both the E-7 and other configurations. Several alternatives were not as well suited to the E-7 characteristics as they would be to an alternative configuration, and vice versa. A large amount of supporting data for each analysis is included.

N88-22894# National Aeronautical Establishment, Ottawa (Ontario).

# THE APPLICATION OF LINEAR MAXIMUM LIKELIHOOD ESTIMATION OF AERODYNAMIC DERIVATIVES FOR THE BELL-205 AND BELL-206

J. H. DELEEUW and K. HUI Oct. 1987 60 p (AD-A191279; NAE-AN-48; NRC-28442) Avail: NTIS HC A04/MF A01 CSCL 01A

Parameter identification from flight test data of fixed-wing aircraft is currently a common procedure for application to aircraft development work, validation of simulation, flight simulator verification, flight control systems synthesis, aircraft handling qualities, flight envelope expansion and airplane certification. Similar work on the identification of the more complex helicopter system is currently still in the research stage. This report describes a number of flight test experiments involving the application of parameter estimation techniques to helicopters in order to determine the stability and control derivatives and to obtain information to identify improvements in the structure of the helicopter model.

N88-22895# Army Aviation Engineering Flight Activity, Edwards AFB. Calif.

AIRWORTHINESS AND FLIGHT CHARACTERISTICS TEST OF A SKI ASSEMBLY FOR THE UH-60A BLACK HAWK HELICOPTER Final Report, for 30 Apr. 1987

RANDALL W. CASON, JOHN I. NAGATA, THOMAS L. REYNOLDS, and DAUMANTS BELTE Aug. 1987 127 p

(AD-A191414) Avail: NTIS HC A07/MF A01 CSCL 01C
An Airworthiness and Flight Characteristics test of the UH-60A
helicopter (S/N 84-23953) configured with a ski assembly was
conducted by the U.S. Army Aviation Engineering Flight Activity.
The test was conducted at the Sikorsky Flight Test Facility at

West Palm Beach, Florida (elevation 28 feet). A total of 25.5 productive flight hours were flown during the period 6 to 30 April, 1987. Tests were conducted to determine the handling qualities and performance decrement of the ski assembly on the UH-60A helicopter at average mission gross weights of approximately 16,000 and 22,000 pounds. The handling qualities of the UH-60A with the ski assembly installed were essentially unchanged from those previously reported for the normal utility UH-60A. Two previously reported shortcomings are still evident: neutral static longitudinal stability during intermediate rated power climbs, and self-excited aircraft pitch oscillation with the collective control raised sufficiently for the aircraft to be light on its wheels. The equivalent flat plate area of the ski assembly was determined to be three sq GRA

# N88-23031# Joint Publications Research Service, Arlington, Va. AIRCRAFT FLIGHT DYNAMICS RESEARCH IN PAST DECADE REVIEWED

LIQIN FAN and QISHUN CHEN In its JPRS Report: Science and Technology. China p 1-8 3 May 1988 Transl. into ENGLISH from Guoji Hangkong (Beijing, People's Republic of China), no. 2, Feb. 1988 p 28-31

Avail: NTIS HC A08/MF A01

Chinese research over the past decade in flight dynamics is reviewed. Areas discussed include research in aircraft flight quality specifications and flight performance specifications, controllable flight dynamics, atmospheric disturbance, study of non-linear characteristics, and development of test research methods.

J.P.B.

# N88-23129# Tracor Hydronautics, Inc., Laurel, Md. AN EXPERIMENTAL STUDY TO DETERMINE THE FLOW AND THE SUBSONIC STATIC AND DYNAMIC STABILITY CHARACTERISTICS OF AIRCRAFT OPERATING AT HIGH ANGLES-OF-ATTACK

ALEX GOODMAN and CLINTON E. BROWN In AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 28 p Jun. 1987

Avail: NTIS HC A20/MF A01

A comprehensive series of experiments was conducted in the Tracor Hydronautics Ship Model Basin (HSMB) to determine the subsonic static and dynamic stability characteristics of a 3.5-foot span, 60-deg delta-high-wing fuselage model operating at high angles-of-attack up to 68 deg. In addition, typical results of flow visualization studies for a range of Reynolds numbers from 0.2 to 1.6 x 10 to the 6th, are presented. Also, the motions, force and moment coefficients resulting from a simulated pitchup maneuver are presented. Described is the HSMB Large Amplitude Horizontal (LAHPMM), Mechanism System Motion delta-wing-fuselage model, model-support systems, and the data acquisition and processing system used. The advantages of performing tests in the HSMB using the LAHPMM technique over existing wind tunnel techniques, such as curved flow and combined oscillation, for determination of the dynamic stability derivatives are presented and discussed. Results compare favorably with earlier (1950) tests of a similar configuration at angles of attack up to 32 deg.

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#### **AIRCRAFT INSTRUMENTATION**

Includes cockpit and cabin display devices; and flight instruments.

A88-38707\*# National Aeronautics and Space Administration.
Flight Research Center, Edwards, Calif.
FORMULATON OF A GENERAL TECHNIQUE FOR
PREDICTING PNEUMATIC ATTENUATION ERRORS IN
AIRBORNE PRESSURE SENSING DEVICES
STEPHEN A. WHITMORE (NASA, Flight Research Center,

Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 40-50. refs (AIAA PAPER 88-2085)

Presented is a mathematical model, derived from the Navier-Stokes equations of momentum and continuity, which may be accurately used to predict the behavior of conventionally mounted pneumatic sensing systems subject to arbitrary pressure inputs. Numerical techniques for solving the general model are developed. Both step and frequency response lab tests were performed. These data are compared against solutions of the mathematical model. The comparisons show excellent agreement. The procedures used to obtain the lab data are described. In-flight step and frequency response data were obtained. Comparisons with numerical solutions of the mathematical model show good agreement. Procedures used to obtain the flight data are described. Difficulties encountered with obtaining the flight data are discussed.

#### A88-38715#

#### METEOPOD, AN AIRBORNE SYSTEM FOR MEASUREMENTS OF MEAN WIND, TURBULENCE, AND OTHER METEOROLOGICAL PARAMETERS

P. VOERSMANN and A. M. HOFF (Aerodata Flugmesstechnik GmbH, Brunswick, Federal Republic of Germany) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 127-132. (AIAA PAPER 88-2103)

An aircraft and helicopter pod construction is presented which contains the aerological sensor hardware for on-board measurements of wind and turbulence. The brief description of the principle of airborne wind determination shows the inherent necessity of precise navigation data in combination with aerological parameters. The METEOPOD system is a compact solution to present the meteorological background to all scientific aircraft users who are concerned with geophysical data being influenced by the atmosphere. Nearly every aircraft including helicopters is suitable for the operation of the pod. The mean and turbulent transport processes can be calculated on-line.

#### A88-38766#

#### **KEYS TO A SUCCESSFUL FLIGHT TEST**

JUDIE FECHTER and CHARLENE MILLS (IBM, Systems Integration Div., Owego, NY) AIAA, Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988. 17 p. refs (AIAA PAPER 88-2174)

An account is given of those test methods and tools that have evolved through flight test experience oriented toward avionics integration in the cases of the U.S. Navy's LAMPS SH-60 Seahawk helicopter, the U.S. Army's HH-60 Nighthawk helicopter, and the MC-130H Combat Talon II aircraft flight test programs. Attention is given to ways of managing different types of test requirements, joint contractor/customer flight test planning and testing responsibilities, the optimum flight test organization, flight card generation, flight test configuration management, and software tools.

#### A88-39495#

#### TAXIWAY SAFETY USING MODE S SSR

[ROLLFELDSICHERUNG AUF DER BASIS VON SSR MODE S] WOLFGANG DETLEFSEN (Braunschweig, Technische Universitaet, Brunswick, Federal Republic of Germany) Ortung und Navigation (ISSN 0474-7550), vol. 29, no. 1, 1988, p. 126-133. In German. refs

The feasibility of using the mode S SSR transponders being installed on transport aircraft to monitor taxiway traffic is investigated. The operational principles of mode S, its advantages over mode A/C, and time-of-flight and triangulation methods for taxiway position determination using the mode S transponder signal are discussed in detail and illustrated with extensive diagrams. The potential problems presented by multipath propagation and the need to differentiate landed and flying aircraft are considered.

The components of a complete taxiway monitoring system include mode S SSR for aircraft, follow-me cars, and emergency vehicles; a radio direction-finding system for other vehicles, a taxiway surveillance radar with digital image processing to detect obstacles, and provision for communicating warnings and taxiway traffic information to the pilot (probably using the data-link functions of mode S SSR).

#### A88-39496#

### A MILLIMETER-WAVE LOW-RANGE RADAR ALTIMETER FOR HELICOPTER APPLICATIONS - EXPERIMENTAL RESULTS

M. LANGE, J. DETLEFSEN, M. BOCKMAIR, and U. TRAMPNAU (Muenchen, Technische Universitaet, Munich, Federal Republic of Germany) Ortung und Navigation (ISSN 0474-7550), vol. 29, no. 1, 1988, p. 138-148.

The design and performance of a high-resolution 35-GHz FM-CW radar altimeter for use in helicopters maneuvering at very low altitudes (e.g., in unpowered emergency landing exercises) are reported. Digital beat-signal processing and spectral analysis are employed to decrease system vulnerability to multitarget situations. The results of experimental trials are presented in extensive graphs and discussed in detail, and it is shown that the attimeter responds to treetops, giving a clear indication of obstacle-free regions below the helicopter. System accuracy is given as + or - 0.1 m at altitude 0-20 m and + or - 1 m at altitude 20-150 m.

#### A88-40517

# REFLECTIONS ON THE INTEGRATION OF AVIONICS EQUIPMENT [REFLEXIONS SUR L'INTEGRATION DES EQUIPEMENTS D'AVIONIQUE]

A. JANEX and J.-C. JOGUET (LMT Radio Professionnelle, Boulogne-Billancourt, France) (Instituts de Navigation, Congres International, Sydney, Australia, Feb. 2-5, 1988) Navigation (Paris) (ISSN 0028-1530), vol. 36, April 1988, p. 180-187. In French.

The integration of various airborne systems is considered. Current integration concepts involve the regrouping of previously separate functions into larger systems such as flight control systems, weapon management systems, and communications, navigation, identification (CNI) systems. CNI systems include UHF communications, TACAN/DME, and IFF. TDMA systems for the integration of CNI functions are also considered. The Pave Pillar system for integrating fighter aircraft avionics includes Integrated Communication, Navigation and Identification Avionics. Other concepts, such as the integration of the INS, GPS, ILS, MLS, VOR, and TACAN navigation systems, and the integration of the V/UHF, JTIDS, and HF communications systems, are considered.

#### A88-40518

### NAVIGATION AND PERFORMANCE COMPUTER [CALCULATEUR DE NAVIGATION ET DE PERFORMANCE]

PAUL CAMUS (Airbus Industrie, Blagnac, France) (Instituts de Navigation, Congres International, Sydney, Australia, Feb. 2-5, 1988) Navigation (Paris) (ISSN 0028-1530), vol. 36, April 1988, p. 188-195. In French.

Aircraft navigation and cockpit data display are reviewed, with emphasis on the Airbus inertial guidance system. The Airbus performance and navigation computer determines the optimum velocity and latitude for each mission and facilitates navigation guidance in four dimensions (the fourth dimension being time), taking traffic constraints into account. Calculations are performed in real time and involve the use of mathematical models for performance optimization, in addition to data on the infrastructure of air routes. Airbus CRT displays include a virtual geographic map showing the route followed, the aircraft velocity, the force and direction of the wind, and the names of points flown over.

R.R.

#### A88-40534#

#### TRENDS AND PROBLEMS OF HEAD-UP DISPLAY

ISAO IWASAKI Japan Society for Aeronautical and Space

Sciences, Journal (ISSN 0021-4663), vol. 36, no. 408, 1988, p. 30-35. In Japanese. refs

#### A88-41096

THE EFFECT OF AIRCRAFT ANGULAR VIBRATIONS ON THE QUALITY OF REMOTELY SENSED IMAGES [DIE WIRKUNG ANGULARER LUFTFAHRZEUGSCHWINGUNGEN AUF DIE BILDDATEN VON FERNERKUNDUNGSSYSTEMEN]

FRANZ PLISCHKE (Interflug Gesellschaft fuer Internationalen Flugverkehr mbH, Berlin, German Democratic Republic) Technisch-oekonomische Information der zivilen Luftfahrt (ISSN 0232-5012), vol. 24, no. 2, 1988, p. 43-47. In German. refs

Aircraft rotational vibration and its effects on the performance of optical and electronic remote-sensing equipment are investigated analytically and experimentally. Expressions describing the rotation about the three aircraft axes are derived and discussed. In the flight tests, photogrammetric cameras and multispectral cameras, whiskbroom and pushbroom scanners, and radars were flown on An-2, L-410 UVP, IL-18, and Mi-8 aircraft under pilot, autopilot, or combined autopilot-pilot control and under different turbulence conditions. A specially developed 1-kg gyroscopic device is used to measure the angular motion in all three axes, both in the aircraft and on the sensor. The results are presented in tables and graphs and shown to be in good general agreement with the theoretical computations. Motion about the longitudinal axis is found to be the dominant cause of image-quality degradation.

#### A88-41098

**AVIONICS FOR TRANSPORT AIRCRAFT - CURRENT** DEVELOPMENT STATUS (AUSRUESTUNG VON VERKEHRSFLUGZEUGEN - STAND DER ENTWICKLUNG]

GUSTAV WESTPHAL (Interflug Gesellschaft fuer Internationalen Flugverkehr mbH, Berlin, German Democratic Republic) Technisch-oekonomische Information der zivilen Luftfahrt (ISSN 0232-5012), vol. 24, no. 2, 1988, p. 76-80. In German.

The technology and capabilities of present and next-generation avionics for transport aircraft are reviewed. Systems for status monitoring, flight control, navigation, communication, flight safety, and special missions are considered, and particular attention is given to computer integration of different onboard systems, the display of systems information in the cockpit, new demands on ATC and the technologies being developed to meet them, the application of satellite-based navigation and emergency position-finding systems, and the maintenance and repair problems posed by the introduction of advanced avionics. Block diagrams and drawings of cockpit displays are provided.

DISPLAY SYSTEM OPTICS; PROCEEDINGS OF THE MEETING, ORLANDO, FL, MAY 21, 22, 1987

ARTHUR COX, ED. (KFO Associates, Inc., Wyckoff, NJ) and RUDOLF HARTMANN, ED. (Martin Marietta Corp., Orlando, FL) Meeting sponsored by SPIE. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Volume 778), 1987, 103 p. For individual items see A88-41362 to A88-41369.

(SPIE-778) The present conference on human vision, image displays, and helmet-mounted displays gives attention to brain organization for visual tasks, the validation of visual cues in flight simulator displays, an eye-tracking joystick, the effects of task training and instructions on visual load, aerial image systems, the suppression of display cockpit reflections, and cockpit readiness for night vision goggles. Also discussed are circular polarization image selection for 'timeplex' stereoscopic video displays, optical design criteria for binocular helmet-mounted displays, the development of a wide-FOV helmet-mounted display for simulators, an integrated approach to helmet display system design, and an innovative, lightweight helmet airborne display and target sight.

#### A88-41366 OPTICAL DESIGN CRITERIA FOR BINOCULAR HELMET-MOUNTED DISPLAYS

MARTIN SHENKER (Farrand Optical Co., Inc., Valhalla, NY) IN: Display system optics; Proceedings of the Meeting, Orlando, FL. May 21, 22, 1987. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1987, p. 70-78.

Binocular helmet-mounted displays have become increasingly popular over the past several years; particular emphasis has been placed on achieving wide field of view displays with resolution capability greater than that attainable with a monocular system utilizing a single CRT. Binocular display systems with severely divergent axes have been developed wherein the horizontal field is divided into three areas, that visible to the right eye only, that visible to the left eye, and an overlap region. A typical system has individual displays with 80-deg fields-of-view with axes turned outward + or - 20 deg achieving a total field of 120 deg with a 40-deg overlap. The turnout of the optical axes means that the center of the display field is 20 deg off-axis in the individual displays. Almost all points in the overlap regions are at significantly different off-axis angles in the two displays. The implications of these factors relative to required aberrational correction and system characteristics are discussed. Author

#### A88-41367 DEVELOPING A WIDE FIELD OF VIEW HMD FOR **SIMULATORS**

BILL MCLEAN and STEVE SMITH (Hamilton Standard, Farmington, CT) IN: Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1987, p. 79-82. refs

An evaluation is made of the design lessons learned during the development of a wide-FOV helmet-mounted display (HMD) by personnel whose expertise ranged over the fields of optics, electronics, mechanical design, video display design, human vision, and composite materials. The HMD's image was produced by two matched high-resolution video cameras fitted with minimum-distortion camera lenses; the device itself was intended to support flight simulation studies for advanced rotary wing applications. In order to increase the horizontal FOV to 120 deg, the right and left images of 80 deg each are overlapped by 40 deg.

#### A88-41368

### AN INTEGRATED APPROACH TO HELMET DISPLAY SYSTEM

JAMES E. MELZER and ERIC W. LARKIN (Kaiser Electronics, Optical and Helmet Systems Dept., San Jose, CA) IN: Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1987, p. 83-88.

The retrofitting of a display apparatus to an existing helmet in order to configure a helmet-mounted display (HMD) has led to shortcommings in system weight, center-of-gravity, obstructions, and head-motion restriction. The present HMD design approach has set out from the development of an optical system having the desired performance characteristics, folding it in a way that conforms to the human head's contours, and then designing the helmet around the optics. The resulting HMD compromises neither helmet life-support functions nor optical operations.

#### A88-41369

#### A LIGHTWEIGHT INNOVATIVE HELMET AIRBORNE DISPLAY AND SIGHT (HADAS)

DANIEL NAOR, ODED ARNON, and ARIE AVNUR (ELOP Electrooptics Industries, Ltd., Defense Systems Div., Rehovot, IN: Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987. Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1987, p. 89-95.

The fighter aircraft pilot Helmet Airborne Display And Sight (HADAS) system combines holographic optical elements and fiber-optics display functions with real-time image processing of helmet location to provide 'all-aspect' HUD performance. In effect, helmet-mounted display and helmet-mounted sight systems are integrated in a single apparatus. Attention is presently given to the complex tradeoff and integration tasks faced by the developers of HADAS in their multidisciplinary research efforts, as well as to the laboratory verification test data obtained for the system to

N88-22896# National Aerospace Lab., Tokyo (Japan). FIRST FLIGHT SIMULATOR TEST OF THE HEAD-UP DISPLAY FOR NAL QSTOL EXPERIMENTAL AIRCRAFT (ASUKA) KEIJI TANAKA, KENJI YAZAWA, and TOSHIHARÙ INAGAKI Oct. 1986 36 p In JAPANESE; ENGLISH summary (DE88-751804; NAL-TM-554) Avail: NTIS (US Sales Only) HC A03

The following evaluation and information were obtained after the approach and landing simulation of Head-up Display HUD: (1) Velocity-Vector (VV) mode: effective for actual landing; easily controllable; landing accuracy is improved, (2) Pseudo-landing mode: effective for actual landing, but visibility of an actual runway deteriorates when the mock runway and the actual one overlap; pseudo-flare and touchdown are not exact; concerning pseudo-landing in the air, effective landing becomes possible, (3) CTOL landing: since the cross-checking load is alleviated and the flight path is accurately controlled, accurate approach becomes possible; Trim vector is effective for controlling speed and attitude and anticipatory control of power becomes feasible through speed vector, (4) STOL landing: when the stability control augmentation system (SCAS) is off, difficulty of lateral control is induced and control load is enhanced. DOF

N88-22897# National Aerospace Lab., Tokyo (Japan). BASIC DESIGN OF A FLIGHT DIRECTOR SYSTEM FOR NAL STOL RESEARCH AIRCRAFT

KEIJI TANAKA 26 p In JAPANESE; ENGLISH Dec. 1986 summary (DE88-751806; NAL-TM-558) Avail: NTIS (US Sales Only) HC A03

A basic design concept of a flight director system (FDS) is developed in an effort to examine backside operations during the approach phase, centering on the transient responses at the time of the shift to the ILS step and the stability during the following steps. This FDS has three commands; pitch command, flight path command, and bank command. Equations are formulated to generate these commands. To determine the flight-director dynamics, models of pilots, FDS and STOL research aircraft are developed on the assumption that they can be connected linearly. and dynamic responses of the entire system are calculated. To set up parameters based on responses of the system, examination is made of a stabilization/control system model, pilot model for pitch control, wash-out time constant of the pitch command loop, pilot model for speed control, glide slope capture characteristics, localizer deviation correction characteristics, and localizer capture characteristics. DOF

N88-22898# Aeritalia S.p.A., Turin (Italy), Gruppo Sistemi Avionics ed Equipaggiamenti.

RAPID PROTOTYPING OF COMPLEX AVIONICS SYSTEM **ARCHITECTURES** 

L. BERARDI, N. GIORGI, W. MELLANO, A. VALANTE, and E. ZUCCO 1987 12 p

(ETN-88-92275) Avail: NTIS HC A03/MF A01
The Expert Consultant for Avionics System Transformation Exploitation was developed for rapidly prototyping different alternatives, and to establish the information flow architecture of the avionics system. The tool provides the user with an interface to assist in describing the avionics from the point of view of the data handling, and presents the results in a suitable format; it performs consistency checks and advises the user on possible architectural problems by means of the expert system techniques. The development environment of the tool and how it works in a consulting session are described.

N88-22899# Strathclyde Univ., Glasgow (Scotland). THE USE OF RULE INDUCTION TO ASSIST IN THE DIAGNOSIS OF AVIONIC CIRCUIT BOARD DEFECTS M.S. Thesis

G. B. SADLER 1987 81 p (ETN-88-92077) Avail: NTIS HC A05/MF A01

An expert system to assist in the diagnosis of avionic circuit board faults was developed using the rule induction package Intelligence-1. The initial attempt at building an expert system failed but when the level of detail of attributes was altered an expert system was successfully built. The method was proved by building an expert system for a second circuit board using the same approach and by reproducing the same rules for the first board using a different rule induction package, IRIS. The expert system built for the first board was evaluated for accuracy by interrogation using data from additional historical examples and for worth by monitored trials. The former show that the expert system is accurate but not complete and the latter is inconclusive.

N88-22900# VDO-Luftfahrtgeraete Werk Adolf Schindling G.m.b.H., Frankfurt (West Germany).

BASIC DESIGN STUDIES FOR THE REALIZATION OF LIQUID CRYSTAL DISPLAY SYSTEMS IN AIRCRAFT Final Report.

HANS WERNER FISCHER Bonn, Fed. Republic of Germany Bundesministerium fuer Forschung und Technologie 75 p In GERMAN; ENGLISH summary (Contract BMFT-LFL-8376-0)

(VA-87-001; ETN-88-92094) Avail: NTIS HC A04/MF A01

A project to make liquid crystal technology available for displays and display systems in the cockpit of aircraft is discussed. This requires technological studies to select the most suitable type of liquid crystal. Specifications regarding contrast and readability for day and night operation have to be met. Corresponding to the actual applications, compromise solutions have to be found by optimization in order to meet additional, partly contrary, demands on the displays. The study of conditions for realizing a complete display system is given priority. It is to represent monitoring data of engines and auxiliary systems as well as warning signals in a helicopter. The design of the displays includes the display case and electronic control allowing for error recognition and reliability. Special difficulties result from requirements for lower weight and low power input.

N88-22901\*# Lockheed-Georgia Co., Marietta. ANALYTICAL SENSOR REDUNDANCY ASSESSMENT Final Report

D. B. MULCARE, L. E. DOWNING, and M. K. SMITH Apr. 1988 44 p

(Contract NAS2-11853)

(NASA-CR-182892; NAS 1.26:182892; DOT/FAA/CT-86/32)

Avail: NTIS HC A03/MF A01 CSCL 01D

The rationale and mechanization of sensor fault tolerance based on analytical redundancy principles are described. The concept involves the substitution of software procedures, such as an observer algorithm, to supplant additional hardware components. The observer synthesizes values of sensor states in lieu of their direct measurement. Such information can then be used, for example, to determine which of two disagreeing sensors is more correct, thus enhancing sensor fault survivability. Here a stability augmentation system is used as an example application, with required modifications being made to a quadruplex digital flight control system. The impact on software structure and the resultant revalidation effort are illustrated as well. Also, the use of an observer algorithm for wind gust filtering of the angle-of-attack sensor signal is presented. **Author** 

#### 07

#### **AIRCRAFT PROPULSION AND POWER**

Includes prime propulsion systems and systems components, e.g., gas turbine engines and compressors; and on-board auxiliary power plants for aircraft.

#### A88-37191

#### ADVANCES IN EJECTOR THRUST AUGMENTATION

PAUL M. BEVILAQUA (Lockheed Aeronautical Systems Co., Marietta, GA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 201-215. refs

(SAE PAPER 872322)

Directing the exhaust of a turbojet engine through an ejector pump can significantly increase the jet thrust. This paper is a review of recent advances in the development of thrust augmenting ejectors for VSTOL aircraft. Progress in developing a theory of ejector operation, and related efforts in analysis and prediction will be summarized. Studies of turbulent mixing and duct design which have led to improvements in ejector performance will also be described. Finally, researach problems of current interest and the likely direction of future airplane programs will be discussed.

Author

#### A88-37192

### ESTIMATION OF THRUST AUGMENTOR PERFORMANCE IN V/STOL APPLICATIONS

T. S. LUND (Purdue University, West Lafayette, IN), D. A. TAVELLA, and L. ROBERTS (Stanford University, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 217-224. refs (SAE PAPER 872323)

The performance of two-dimensional thrust augmentors was analyzed by a viscous-inviscid approach, where distinct zones of the augmentor flow-field treated with efficient methodologies, and are then matched together by satisfying required pressure and velocity continuity at zone interfaces. This efficient approach was applied both to a parametric analysis of a standard ejector configuration, where various shroud parameters for arrangements with one or two primary nozzles were considered, and to a limited constrained optimization analysis of inlet shape and nozzle location for a single primary nozzle arrangement. The methodology was validated by quantitative and qualitative comparison with experimental results, and the study provided new insights into thrust augmentor performance as well as practical design quidelines.

A88-37193 De Havilland Aircraft Co. of Canada Ltd., Downsview (Ontario).

### DEVELOPMENT OF LIFT EJECTORS FOR STOVL COMBAT AIRCRAFT

D. B. GARLAND (de Havilland Aircraft Company of Canada, Downsview) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 225-234. Research supported by the Canadian Department of Industry, Trade and Commerce, DND, and NASA. refs (SAE PAPER 872324)

This paper reviews ejector development at de Havilland Canada (DHC) over the past 25 years, and focuses on the features proposed for the E7 wind tunnel model. The E7 aircraft is a STOVL project study design which utilizes lift ejector technology developed by DHC. Efforts to maximize thrust augmentation ratio within the packaging constraints of typical STOVL aircraft configurations are described. Experimental results from antecedents of the E7 ejector are presented, together with the latest results from full-scale tests at Lewis Research Center, NASA. The major geometrical

parameters are described, and their influence on thrust augmentation evaluated. Various nozzle types are discussed. Performance is compared with theoretical trends derived from global compressible theory. A brief look at the installation aerodynamics of a pair of chordwise ejectors, in hover, completes the paper.

#### A88-37196

#### THRUST EFFICIENCY OF POWERED LIFT SYSTEMS

JOHN L. LOTH and MATHEW FUNK (West Virginia University, Morgantown) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 253-262. Research supported by the Lockheed-Georgia Co. refs (SAE PAPER 872327)

Two efficiencies have been introduced to facilitate the comparison of powered high lift systems for low approach speed and for acceleration after lift-off. The corresponding minimum thrust and total impulse required by an idealized unpowered wing are used as reference parameters. The efficiencies are shown as a function of installed thrust to weight ratio and minimum flight speed, non-dimensionalized by a reference velocity with dynamic pressure equal to the wing loading. Incorporated in the efficiencies are the effects of wing aerodynamics, engine thrust loss due to power extraction, duct loss and thrust recovery.

**A88-37199\*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

### FLIGHT PROPULSION CONTROL INTEGRATION FOR V/STOL AIRCRAFT

JAMES R. MIHALOEW (NASA, Lewis Research Center, Cleveland, OH) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 303-315. Previously announced in STAR as N88-11680. refs (SAE PAPER 872330)

The goal of the propulsion community is to have the enabling propulsion technologies in place to permit a low risk decision regarding the initiation of a research STOVL supersonic attack fighter aircraft in the mid-1990's. This technology will effectively integrate, enhance, and extend the supersonic cruise, STOVL, and fighter/attack programs to enable U.S. industry to develop a revolutionary supersonic short takeoff vertical landing fighter/attack aircraft in the post-ATF period. The rationale, methods, and criteria used in developing a joint NASA Lewis and NASA Ames research program to develop the technology element for integrated flight propulsion control through integrated methodologies is presented. This program, the Supersonic STOVL integrated Flight Propulsion Controls Program, is part of the overall NASA Lewis Supersonic STOVL integrated approach to an integrated program to achieve integrated flight propulsion control technology.

#### A88-37213

#### LIFT ENGINES - APPLIED HISTORY

H. M. HARVEY (Rolls-Royce, PLC, Derby, England) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 467-476. (SAE PAPER 872347)

A historical overview is given of lift engines with particular attention given to VTOL. The RB 108, RB 162, and XJ 99 engines are described in detail. Technical experience is discussed with emphasis placed on thrust, weight, volume, intakes, engine stability, stability validation, exhaust gas recirculation, and ground erosion. It is shown that that VTOL aircraft with composite powerplants can be designed and operated successfully.

K.K.

#### A88-37214

#### STOVL RCS EFFECTS ON PROPULSION SYSTEM DESIGN

LEE COONS (Pratt and Whitney, West Palm Beach, FL) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of

Automotive Engineers, Inc., 1988, p. 477-482. USAF-supported research.

(SAE PAPER 872349)

The reaction control system (RCS) requirements for advanced vertical landing/takeoff aircraft are discussed. It is noted that each aircraft may have differing RCS control requirements resulting in engine bleed flow and pressure requiremets being a function of aircraft design. Consideration is given to projected advanced vertical landing/takeoff missions designed to maintain air superiority near the forward edge of the battle area. RCS thrust/bleed requirements and combustor temperature compensation are addressed as well as the impact of RCS bleed requirements on integrated propulsion/bleed system, and the impact of high levels of bleed air.

**A88-37215\*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

### NASA SUPERSONIC STOVL PROPULSION TECHNOLOGY PROGRAM

PETER G. BATTERTON and BERNARD J. BLAHA (NASA, Lewis Research Center, Cleveland, OH) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 483-494. Previously announced in STAR as N88-14093. refs

(SAE PAPER 872352)

Supersonic capable STOVL fighter/attack aircraft can provide capabilities for close support and air superiority which will be highly desirable in the future. Previous papers in this session described the historical aspects, trade-offs, and requirements for powered lift propulsion systems, and it is shown that propulsion technology is more key to the success of this type of aircraft than for any previous fighter/attack aircraft. The NASA Lewis Research Center program activities which address required propulsion technology development are discussed. Several elements of this program were initiated which address hot gas ingestion and ejector augmenter performance and some preliminary results are shown. In addition, some additional near-term research activity plans and the new Powered Lift Facility (PLF) research capability are presented.

Author

**A88-37217\*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

TEST STAND PERFORMANCE OF A CONVERTIBLE ENGINE FOR ADVANCED V/STOL AND ROTORCRAFT PROPULSION JACK G. MCARDLE (NASA, Lewis Research Center, Cleveland, OH) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 507-517. Previously announced in STAR as N88-11679. refs (SAE PAPER 872355)

A variable inlet guide vane (VIGV) convertible engine that could be used to power future high-speed V/STOL and rotorcraft was tested on an outdoor stand. The engine ran stably and smoothly in the turbofan, turboshaft, and dual (combined fan and shaft) power modes. In the turbofan mode with the VIGV open, fuel consumption was comparable to that of a conventional turbofan engine. In the turboshaft mode with the VIGV closed, fuel consumption was higher than that of present turboshaft engines because power was wasted in churning fan-tip air flow. In dynamic performance tests with a specially built digital engine control and using a waterbrake dynamometer for shaft load, the engine responded effectively to large steps in thrust command and shaft

# **A88-37228** Department of National Defence, Ottawa (Ontario). THE SYNTHESIS OF EJECTOR LIFT/VECTORED THRUST FOR STOVL

P. R. SULLY (DND, Ottawa, Canada) and D. C. WHITTLEY IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 657-667. Research sponsored

by de Havilland Aircraft Company of Canada, Department of Regional Industrial Expansion, DND, and NASA. refs (SAE PAPER 872378)

Fundamentals of powered lift for STOL and STOVL are discussed, and the development of Ejector Lift/Vectored Thrust (EL/VT) for multirole supersonic fighter aircraft is considered. Principles of the chordwise ejector concept are reviewed, and a baseline EL/VT layout for the current STOVL studies is proposed. Advantages of the EL/VT concept include that it is not susceptible to hot gas reingestion, that fore and aft distribution of jet lift permits longitudinal distribution of aerodynamic lift and therefore a low level of supersonic wave drag, and that thrust augmentation without fuel consumption permits a more sustained hover.

**A88-37237\*** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

### IMPACT OF BYPASS RATIO ON THRUST-TO-WEIGHT FOR V/STOL

SAMUEL WILSON (NASA, Ames Research Center, Moffett Field, CA) and KATHLEEN MAHONEY (Grumman Aerospace Corp., Bethpage, NY) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 785-795. refs

(SAE PAPER 872348)

Issues involved in the selection of a V/STOL propulsion system are discussed. The effect of bypass ratio on thrust-to-weight, fuel flow, and hover efficiency is investigated for the cases of four representative tilt propulsion system aircraft. The effect of fan pressure ratio on engine selection is shown to be very mission dependent. It is noted that the FAA requires reserves based on fixed wing or helicopter operations, neither of which is found to be entirely appropriate for STOVL aircraft.

#### A88-37543

NUMERICAL CALCULATIONS OF THE NATURAL VIBRATIONS OF TURBOMACHINE BLADES USING THE FINITE ELEMENT METHOD [CHISLENNYE RASCHETY SOBSTVENNYKH KOLEBANII LOPATOK TURBOMASHIN S ISPOL'ZOVANIEM MKF1

O. V. REPETSKII (Irkutskii Politekhnicheskii Institut, Irkutsk, USSR) Problemy Prochnosti (ISSN 0556-171X), April 1988, p. 31-36. In Russian.

Finite elements for calculating the vibrations of compressor and turbine rotor blades on the basis of shell theory are described. Calculations are carried out for wide-chord and cooled blades, shrouded blades, and blades with antivibration flanges. The numerical calculations are in good agreement with experimental data and other solutions.

V.L.

# A88-37947\*# General Electric Co., Cincinnati, Ohio. SCALE MODEL ACOUSTIC TESTING OF COUNTERROTATING FANS

B. A. JANARDAN, S. CHUANG, P. Y. HO, and R. LEE (General Electric Co., Cincinnati, OH) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 402-411. refs (Contract NAS3-24080)

(AIAA PAPER 88-2057)

The UDF contrarotating propfan has been subjected to scale model wind tunnel testing to ascertain both general performance and acoustic characteristics data bases. Model Propulsion Simulator test rigs able to mount contrarotating fan blades of up to 24.5-inch diameter were used, and one of these was installed in a large anechoic test chamber for acoustic measurement of conditions simulating representative takeoffs, power cutbacks, and landing approaches. Attention is presently given to the data acquisition/reduction systems, the scaling criteria used to obtain engine size acoustic data, and comparisons with demonstrator aircraft in-flight acoustic test results.

#### A88-39133

#### CONTROL OF AN AIRCRAFT ELECTRIC FUEL PUMP DRIVE

JIMMIE J. CATHEY (Kentucky, University, Lexington) and JOSEPH A. WEIMER (USAF, Aero Propulsion Laboratory, Wright-Patterson AFB, OH) IEEE Transactions on Aerospace and Electronics Systems (ISSN 0018-9251), vol. 24, March 1988, p. 171-176.

(Contract F33651-81-C-2011)

The concept of designing a high-speed, permanent magnet, brushless DC motor aircraft fuel pump drive using a cycloconverter link is examined. A combination of sinusoidal and DC steady-state analysis is used to produce a simple model of the system. A closed-loop control system with an outer loop based on speed and an inner loop based on current is postulated wherein a proportional-plus-integral controller is placed in the forward path to assure minimum speed error. Gains are then set to assure that the eigenvalues of the linearized control system lie within the left half s-plane over the entire full range.

#### A88-39276

#### **COOL EUROPEAN**

ALAN POSTLETHWAITE Flight International (ISSN 0015-3710), vol. 133, May 7, 1988, p. 26-29, 32.

The RTM.322 helicopter turboshaft power plant, while currently producing 2100 shp, is being offered to current users of the more technologically mature T700 turboshaft on the strength of the 40-percent power output growth potential inherent in its state-of-the-art design. The discrepancy in output growth is due to the T700's reaching of its turbine inlet temperature limit. The RTM.322's 3000-parts count is claimed to be lower than that of the T700 by some 1500 parts. Both turboshaft and turboprop versions of the engine are under consideration; the turboshaft may be incorporated by such helicopters as the EH.101, UH-60, and AH-64.

**A88-39707\*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

TURBOFAN ENGINE CORE NOISE SOURCE DIAGNOSTICS ALLEN M. KARCHMER (NASA, Lewis Research Center, Cleveland, OH) IN: NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, State College, PA, June 8-10, 1987. Poughkeepsie, NY, Noise Control Foundation, 1987, p. 121-128.

refs

The paper describes a turbofan-engine measurement program utilizing a variety of diagnostic techniques to identify a source of core-generated noise which contributes to the overall external engine noise characteristics. Included in the turbofan engine diagnostics are data examination, time domain correlation, and frequency domain analysis. It is found that the turbulent pressure fluctuations within the combustor are a source for core noise which propagates through the nozzle and radiates to the far-field. K.K.

A88-40554\* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

### AN OVERVIEW OF ROTORCRAFT PROPULSION RESEARCH AT LEWIS RESEARCH CENTER

ROBERT C. BILL, GILBERT J. WEDEN (NASA, Lewis Research Center; U.S. Army, Propulsion Directorate, Cleveland, OH), and JOHN J. COY (NASA, Lewis Research Center, Cleveland, OH) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 24-31.

Rotorcraft propulsion research at Lewis Research Center is discussed, stressing programs in four areas of component research: compressors, combustors, turbines and transmissions, and three developmental programs: the Small Turboshaft Engine Research (STER) Project, the Advanced Rotorcraft Transmission (ART) program, and the Compound Cycle Engine (CCE) program. The component research emphasizes special problems of turboshaft engines in the 5 lb/sec to 30 lb/sec range. The objectives of the STER program are to evaluate the application of advanced concepts to small turboshaft engine systems and to investigate system related phenomena, such as distortion effects and secondary flow phenomena. The goals of the ART program are to reduce transmission weight by 25 percent, noise generation by

10 dB and mean time between removal to 5,000 hrs. The CCE program is working to combine the airflow capacity and light-weight features of a gas turbine with the more efficient, but heavier diesel turbine.

#### A88-40563

### ALLISON GAS TURBINE - IN THE FOREFRONT OF VERTICAL FLIGHT PROPULSION R&D

LOUIS SCIPIONI, JR. (General Motors Corp., Allison Gas Turbine Div., Washington, DC) Vertiflite (ISSN 0042-4455), vol. 34, May-June 1988, p. 116-120.

R&D work on the T800 engine for the Light Helicopter Experimental (LHX) and the T406 turboshaft engine for the V-22 Osprey TiltRotoris discussed. Materials being studied for these engines include improved high-temperature materials such as metal matrix composites, titanium aluminide, and ceramics. Research on engine components includes work on inlet particle separators, sensor development, integration of the propulsion control with the flight control system, and use of CFD in aerothermal analysis. Work is being done to improve maintainability of both engines, using the Engine Monitoring System (EMS) to provide constant information on engine health and computer aided design to allow for development of simplified assembly and disassembly procedures.

# N88-22034# Naval Postgraduate School, Monterey, Calif. HEAT TRANSFER MODELING OF JET VANE THRUST VECTOR CONTROL (TVC) SYSTEMS M.S. Thesis MICHAEL F. DULKE Dec. 1987 169 p (AD-A190106) Avail: NTIS HC A08/MF A01 CSCL 21E

The research presented herein, analyzes two models of a jet vane Thrust Vector Control (TVC) System. Computational modeling was accomplished using the latest version of the PHEONICS computer code, designated PHEONICS-84. The vane configurations studies, consisted of a simple wedge and a blunt bodied vane, with a leading edge radius of 1.016 mm (1/25 in.). These models were examined in a two dimensional, subsonic and supersonic, cold flow field, for both laminar and turbulent flow cases. Results consist of a numerical solution and a graphical representation of surface shear stress coefficient, Stanton number and convective heat transfer coefficient.

N88-22035# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

LINEAR STATE SPĂCE MODELING OF A TURBOFAN ENGINE Final Report, May 1986 - Dec. 1987

GREGORY L. THELEN Dec. 1987 84 p

(AD-A190110; AFIT/GA/AA/87D-10) Avail: NTIS HC A05/MF A01 CSCL 21E

The F101 turbofan engine, used on the B-1B bomber, will be used as the example with the linear state space models being derived from the non-linear F101 engine computer simulation model. The internal convergence logic of the F101 engine simulation will be used to derive the individual elements making up the linear state space models. The linear state space models will consist of both high speed and low speed rotor dynamics and turbine inlet temperature heat soak dynamics. State space inputs considered will be fuel flow and engine exit nozzle area. Also disussed in this paper will be linear analytic equations in state space format and their comparative accuracies to the models derived using the F101 non-linear computer simulation model. Based on the linear state space models developed in this paper, control systems will be designed and implemented into the F101 engine computer model. Transient performance will be compared between current engine control design and the control design based on the linear state space models. Final results will confirm the validity of the state space models derived by showing improvement GRA over current engine transient performance.

N88-22036# Purdue Univ., West Lafayette, Ind. Thermal Sciences and Propulsion Center.

RESEARCH AS PART OF THE AIR FORCE IN AERO PROPULSION TECHNOLOGY (AFRAPT) PROGRAM Annual Summary Report, Aug. 1986 - Aug. 1987

SANFORD FLEETER Aug. 1987 5 p

(Contract AF-AFOSR-0305-86)

(AD-A190336; AFOSR-87-1763TR) Avail: NTIS HC A02/MF A01 CSCL 01C

Seven students participated in the Air Force Research in Aero Propulsion Technology (AFRAPT) program during the 1986 to 1987 academic year. During this year: one new Ph.D. candidate successfully completed his qualifying exams and initiated his thesis research; one continuing M.S.M.E. candidate has nearly completed his experimental thesis research; five new M.S.M.E. candidates have completed most of their course work and have initiated their thesis research.

N88-22037\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

#### SMALL ENGINE COMPONENTS TEST FACILITY TURBINE **TESTING CELL**

BRENT C. NOWLIN and VINCENT G. VERHOFF Prepared for presentation at the 24th Joint Propulsion Conference. Boston, Mass., 11-13 Jul. 1988; sponsored in part by AIAA, ASEE, ASME, and SAE

(NASA-TM-100887; E-4120; NAS 1.15:100887; AIAA-88-2963) Avail: NTIS HC A03/MF A01 CSCL 21E

NASA Lewis Research Center has designed and constructed a new state-of-the-art test facility. This facility, called the Small Engine Components Test Facility (SECTF), is used to test gas turbines and compressors at conditions similar to actual engine conditions. The SECTF is comprised of two separate facilities - a turbine test cell and a compressor test cell. The paper will describe the turbine test cell. The capabilities of the facility make it unique - no other facility of its kind is capable of combining its pressure. speed, and temperature ranges. Turbine inlet air ranges up to 9 atm (125 psig). The turbine exhaust pressure ranges from 0.15 atm (2 psia) to atmospheric pressure. Turbine inlet air temperatures range from ambient to 700 K (1260 deg R). The controllable speed of the turbine rotor ranges from 4000 to 60,000 rpm and the maximum power absorbed by the facility dynamometer is 1250 hp. The data acquisition system scans up to 2000 channels/sec. This paper will discuss in detail the capabilities of the facility. overall facility design, instrumentation used in the facility, and the data acquisition system. Actual research data is not discussed.

N88-22383\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

#### HIGH-TEMPERATURE COMBUSTOR LINER TESTS IN STRUCTURAL COMPONENT RESPONSE TEST FACILITY

PAUL E. MOORHEAD In its Lewis Structures Technology, 1988. Volume 2: Structural Mechanics p 5-13 May 1988 Avail: NTIS HC A14/MF A01 CSCL 21E

Jet engine combustor liners were tested in the structural component response facility at NASA Lewis. In this facility combustor liners were thermally cycled to simulate a flight envelope of takeoff, cruise, and return to idle. Temperatures were measured with both thermocouples and an infrared thermal imaging system. A conventional stacked-ring louvered combustor liner developed a crack at 1603 cycles. This test was discontinued after 1728 cycles because of distortion of the liner. A segmented or float wall combustor liner tested at the same heat flux showed no significant change after 1600 cycles. Changes are being made in the facility to allow higher temperatures.

N88-22384\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

#### LIFE ASSESSMENT OF COMBUSTOR LINER USING UNIFIED **CONSTITUTIVE MODELS**

M. T. TONG (Sverdrup Technology, Inc., Cleveland, Ohio.) and R. L. THOMPSON In its Lewis Structures Technology, 1988. Volume 2: Structural Mechanics p 15-25 May 1988 (Contract NAS3-24105) Avail: NTIS HC A14/MF A01 CSCL 21E

Hot section components of gas turbine engines are subject to severe thermomechanical loads during each mission cycle. Inelastic deformation can be induced in localized regions leading to eventual fatigue cracking. Assessment of durability requires reasonably accurate calculation of the structural response at the critical location for crack initiation. In recent years nonlinear finite element computer codes have become available for calculating inelastic structural response under cyclic loading. NASA-Lewis sponsored the development of unified constitutive material models and their implementation in nonlinear finite element computer codes for the structural analysis of hot section components. These unified models were evaluated with regard to their effect on the life prediction of a hot section component. The component considered was a gas turbine engine combustor liner. A typical engine mission cycle was used for the thermal and structural analyses. The analyses were performed on a CRAY computer using the MARC finite element code. The results were compared with laboratory test results, in terms of crack initiation lives.

N88-22390\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

#### THE COMPOSITE BLADE STRUCTURAL ANALYZER (COBSTRAN)

ROBERT A. AIELLO In its Lewis Structures Technology, 1988. Volume 2: Structural Mechanics p 83-97 May 1988 Avail: NTIS HC A14/MF A01 CSCL 21E

The use and application of the COBSTRAN (COmposite Blade STRuctural ANalyzer) computer code is presented. COBSTRAN was developed at NASA-Lewis and is currently being used for the design and analysis of aircraft engine ducted and unducted fan blades. The features of COBSTRAN are demonstrated for the modeling and analysis of a scaled down wind tunnel model propfan blade made from fiber composites. Comparison of analytical and experimental mode shapes and frequencies are shown, verifying the model development and analysis techniques used. The methodologies and programs developed for this analysis are directly applicable to other propfan blades.

N88-22394\*# MARC Analysis Research Corp., Palo Alto, Calif. MHOST: AN EFFICIENT FINITE ELEMENT PROGRAM FOR **INELASTIC ANALYSIS OF SOLIDS AND STRUCTURES** 

S. NAKAZAWA In NASA. Lewis Research Center, Lewis Structures Technology, 1988. Volume 2: Structural Mechanics p 131-140 May 1988

(Contract NAS3-23698)

Avail: NTIS HC A14/MF A01 CSCL 21E

An efficient finite element program for 3-D inelastic analysis of gas turbine hot section components was constructed and validated. A novel mixed iterative solution strategy is derived from the augmented Hu-Washizu variational principle in order to nodally interpolate coordinates, displacements, deformation, strains, stresses and material properties. A series of increasingly sophisticated material models incorporated in MHOST include elasticity, secant plasticity, infinitesimal and finite deformation plasticity, creep and unified viscoplastic constitutive model proposed by Walker. A library of high performance elements is built into this computer program utilizing the concepts of selective reduced integrations and independent strain interpolations. A family of efficient solution algorithms is implemented in MHOST for linear and nonlinear equation solution including the classical Newton-Raphson, modified, quasi and secant Newton methods with optional line search and the conjugate gradient method.

Author

N88-22399\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

COMPUTATIONAL STRUCTURAL MECHANICS FOR ENGINE **STRUCTURES** 

CHRISTOS C. CHAMIS In its Lewis Structures Technology, 1988.

Volume 2: Structural Mechanics p 189-203 May 1988 Avail: NTIS HC A14/MF A01 CSCL 21E

The computational structural mechanics (CSM) program at Lewis encompasses the formulation and solution of structural mechanics problems and the development of integrated software systems to computationally simulate the performance, durability, and life of engine structures. It is structured to supplement, complement, and, whenever possible, replace costly experimental efforts. Specific objectives are to investigate unique advantages of parallel and multiprocessing for reformulating and solving structural mechanics and formulating and solving multidisciplinary mechanics and to develop integrated structural system computational simulators for predicting structural performance, evaluating newly developed methods, and identifying and prioritizing improved or missing methods.

N88-22431\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

### REVIEW AND ASSESSMENT OF THE HOST TURBINE HEAT TRANSFER PROGRAM

HERBERT J. GLADDEN In its Lewis Structures Technology, 1988. Volume 3: Structural Integrity Fatigue and Fracture Wind Turbines HOST p 349-367 May 1988

Avail: NTIS HC A16/MF A01 CSCL 21E

The objectives of the HOST Turbine Heat Transfer subproject were to obtain a better understanding of the physics of the aerothermodynamic phenomena occurring in high-performance gas turbine engines and to assess and improve the analytical methods used to predict the fluid dynamics and heat transfer phenomena. At the time the HOST project was initiated, an across-the-board improvement in turbine design technology was needed. Therefore, a building-block approach was utilized, with research ranging from the study of fundamental phenomena and analytical modeling to experiments in simulated real-engine environments. Experimental research accounted for 75 percent of the project, and analytical efforts accounted for approximately 25 percent. Extensive experimental datasets were created depicting the three-dimensional flow field, high free-stream turbulence, boundary-layer transition, blade tip region heat transfer, film cooling effects in a simulated engine environment, rough-wall cooling enhancement in a rotating passage, and rotor-stator interaction effects. In addition, analytical modeling of these phenomena was initiated using boundary-layer assumptions as well as Navier-Stokes solutions.

N88-22902\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

### NASA ADVANCED TURBOPROP RESEARCH AND CONCEPT VALIDATION PROGRAM

JOHN B. WHITLOW, JR. and G. KEITH SIEVERS 1988 23 p Proposed for presentation at the 1988 Conference and Exposition on Future Transportation Technology, San Francisco, Calif., 8-11 Aug. 1988; sponsored by the Society of Automotive Engineers (NASA-TM-100891; E-4129; NAS 1.15:100891) Avail: NTIS HC A03/MF A01 CSCL 21E

NASA has determined by experimental and analytical effort that use of advanced turboprop propulsion instead of the conventional turbofans in the older narrow-body airline fleet could reduce fuel consumption for this type of aircraft by up to 50 percent. In cooperation with industry, NASA has defined and implemented an Advanced Turboprop (ATP) program to develop and validate the technology required for these new high-speed, multibladed, thin, swept propeller concepts. This paper presents an overview of the analysis, model-scale test, and large-scale flight test elements of the program together with preliminary test results, as available.

N88-23247\*# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

### AEROELASTIC FORCED RESPONSE ANALYSIS OF TURBOMACHINERY

TODD E. SMITH (Sverdrup Technology, Inc., Cleveland, Ohio.) In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 287-297 May 1988 (Contract NAS3-24105)

Avail: NTIS HC A20/MF A01 CSCL 21E

An introduction is given to the research activity that is underway to enable the prediction of turbomachinery aeroelastic forced response. An effort is being made to assemble a computer program (FREPS) which incorporates the aeroelastic structural models, unsteady aerodynamic models, and forcing function models. The structural and aerodynamic models are currently well developed. The forcing function models are at a primitive level. A significant activity has begun to identify the forcing functions due to stator-rotor aerodynamic interaction.

#### 08

#### AIRCRAFT STABILITY AND CONTROL

Includes aircraft handling qualities; piloting; flight controls; and autopilots.

A88-37198\* National Aeronautics and Space Administration.
Ames Research Center, Moffett Field, Calif.
INTEGRATED CONTROL AND DISPLAY RESEARCH FOR

TRANSITION AND VERTICAL FLIGHT ON THE NASA V/STOL
RESEARCH AIRCRAFT (VSRA)

JOHN D. FOSTER, ERNESTO MORALEZ, III, JAMES A. FRANKLIN (NASA, Ames Research Center, Moffett Field, CA), and JEFFREY A. SCHROEDER (NASA, Ames Research Center; U.S. Army, Aviation Research and Technology Activity, Moffett Field, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 279-301. Previously announced in STAR as N88-13359. refs (SAE PAPER 872329)

Results of a substantial body of ground-based simulation experiments indicate that a high degree of precision of operation for recovery aboard small ships in heavy seas and low visibility with acceptable levels of effort by the pilot can be achieved by integrating the aircraft flight and propulsion controls. The availability of digital fly-by-wire controls makes it feasible to implement an integrated control design to achieve and demonstrate in flight the operational benefits promised by the simulation experience. It remains to validate these systems concepts in flight to establish their value for advanced short takeoff vertical landing (STOVL) aircraft designs. This paper summarizes analytical studies and simulation experiments which provide a basis for the flight research program that will develop and validate critical technologies for advanced STOVL aircraft through the development and evaluation of advanced, integrated control and display concepts, and lays out the plan for the flight program that will be conducted on NASA's V/STOL Research Aircraft (VSRA).

#### A88-37200

#### THE VAAC VSTOL FLIGHT CONTROL RESEARCH PROJECT

O. P. NICHOLAS (Royal Aircraft Establishment, Bedford, England) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 317-322. (SAE PAPER 872331)

Flight control systems for advanced VSTOL aircraft present unique challenges and opportunities. The designer must address a broad range of questions on control laws, displays and inceptors (cockpit controls). VAAC is a programme of research into advanced VSTOL flight control. Its objective is to develop concepts, and design and assessment techniques. It takes studies through piloted ground-based simulation to flight in the RAE VAAC research Harrier. The experimental flight control system fitted to the VAAC aircraft has been designed to permit a wide range of experimental laws to be flown safely.

#### A88-37201

### A HIGHLY MONITORED AV-8B HARRIER II DIGITAL FLIGHT CONTROL SYSTEM

V. L. MIGBEE, G. G. GASTON, and K. W. GIBBAR (McDonnell Douglas Corp., Saint Louis, MO) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 323-335. (SAE PAPER 872332)

The AV-8B Harrier II incorporates a limited-authority digital Stability Augmentation and Attitude Hold System (SAAHS); this single-channel electronic flight control system requires a self-test/monitoring system that is implemented in three primary categories: hardware, software monitor of hardware, and software monitor of performance. Overall system health is determined by preflight BIT. System performance during flight is continuously monitored. The SAAHS meets the requirement for detection of 98 percent of all possible failures, and isolation of 99 percent of detected failures to a faulty weapons-replaceable assembly in the ground BIT mode.

O.C.

#### A88-37203

### STABILITY AND CONTROL AUGMENTATION SYSTEM OF 'ASKA'

NORIAKI OKADA, TOSHIO BANDO (National Aerospace Laboratory, Chofu, Japan), OSAMU KOBAYASHI, and TAKASHI TSUJIMOTO (Kawasaki Heavy Industries, Ltd., Kobe, Japan) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 349-355. refs (SAE PAPER 872334)

'ASKA' is a STOL airplane with Upper Surface Blown (USB) flaps and is used to perform research on powered lift technology by Japan's National Aerospace Laboratory. ASKA has four high bypass ratio turbofan engines mounted above and forward of the wings, hydraulically actuated flight controls, and the Stability and Control Augmentation System (SCAS). The SCAS is a triple-redundant system with three digital computers. In order to develop and evaluate its control laws, flight simulator tests have been conducted for 9 years during the design phase. Four flights have been devoted to evaluate functions of the SCAS and the control laws. The significant features of the control laws are to realize satisfactory flying qualities in the deep backside region at low airspeeds. As ASKA has not been tested in such regions up to present, this paper includes only the design features of the SCAS control laws, the results of the flight simulator tests, and interim outcomes of the flight tests on shallow USB flap configurations. Author

#### A88-38191#

### A STUDY OF DIGITAL FLY-BY-WIRE CONTROL SYSTEM DESIGN FOR ELASTIC AIRCRAFT

LICHUN LI (Institute of Automatic Flight Control Systems, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Feb. 1988, p. B41-B50. In Chinese, with abstract in English

Design research on the aeroservoelastic effects of a high-performance aircraft using ACT is presented. The method of analysis and design of a DFBW control system and the structure modes of aircraft are considered. The caulping equations which separate the general equations into rigid and structure modes are established. The elastic transfer function of the main internal loop of DBW systems is introduced for a typical first-order longitudinal fuselage bending mode. A design example using the reference aircraft is given.

#### A88-38192#

#### CONTROL LAW DESIGN OF A CCV AIRPLANE

GANG FENG (Nanjing Aeronautical Institute, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Feb. 1988, p. B51-B57. In Chinese, with abstract in English.

In this paper, a method is presented for the design of control

laws of a CCV airplane via eigenstructure assignment, i.e., the eigenvectors of a closed-loop system are selected to decouple the corresponding states of the aircraft, and to realize the CCV control laws of the airplane. The controllers of pitch-pointing and vertical translation modes are designed for an airplane. The simulation results of two modes are excellent.

Author

A88-38737\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

#### EFFECTS OF MANEUVER DYNAMICS ON DRAG POLARS OF THE X-29A FORWARD-SWEPT-WING AIRCRAFT WITH AUTOMATIC WING CAMBER CONTROL

JOHN W. HICKS and BRYAN J. MOULTON (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 312-322. refs

(AIAA PAPER 88-2144)

The camber control loop of the X-29A FSW aircraft was designed to furnish the optimum L/D for trimmed, stabilized flight. A marked difference was noted between automatic wing camber control loop behavior in dynamic maneuvers and in stabilized flight conditions, which in turn affected subsonic aerodynamic performance. The degree of drag level increase was a direct function of maneuver rate. Attention is given to the aircraft flight drag polar effects of maneuver dynamics in light of wing camber control loop schedule. The effect of changing camber scheduling to better track the optimum automatic camber control L/D schedule is discussed.

**A88-38747\***# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

### PERFORMANCE IMPROVEMENTS OF AN F-15 AIRPLANE WITH AN INTEGRATED ENGINE-FLIGHT CONTROL SYSTEM

LAWRENCE P. MYERS and KEVIN R. WALSH (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 410-418. refs (AIAA PAPER 88-2175)

An integrated flight and propulsion control system has been developed and flight demonstrated on the NASA Ames-Dryden F-15 research aircraft. The highly integrated digital control (HIDEC) system provides additional engine thrust by increasing engine pressure ratio (EPR) at intermediate and afterburning power. The amount of EPR uptrim is modulated based on airplane maneuver requirements, flight conditions, and engine information. Engine thrust was increased as much as 10.5 percent at subsonic flight conditions by uptrimming EPR. The additional thrust significantly improved aircraft performance. Rate of climb was increased 14 percent at 40,000 ft and the time to climb from 10.000 to 40.000 ft was reduced 13 percent. A 14 and 24 percent increase in acceleration was obtained at intermediate and maximum power, respectively. The HIDEC logic performed fault free. No engine anomalies were encountered for EPR increases up to 12 percent and for angles of attack and sideslip of 32 and 11 deg, respectively. Author

#### A88-39485

#### COMPUTER VISION FOR FLIGHT VEHICLES

E. D. DICKMANNS (Muenchen, Universitaet der Bundeswehr, Neubiberg, Federal Republic of Germany) Zeitschrift fuer Flugwissenschaften und Weltraumforschung (ISSN 0342-068X), vol. 12, Mar.-Apr. 1988, p. 71-79. refs

The application of computer vision (CV) to aircraft is discussed, with a focus on a CV system for the final landing approach. The history and fundamental principles of CV are reviewed; advances in computing power, Al, and sensor technology are described; and applications such as on-request crew support, independent monitoring, improved autopilots, landmark navigation, and advanced RPVs are briefly characterized. Particular attention is given to real-time numerical simulations of 60-70-m/sec business-jet landing approaches, performed at the Universitaet der

Bundeswehr in Munich. In these simulations, feature-based image processing using an appropriately defined world model is realized with a cycle time of 100 msec, and the only additional input to the landing control is the airspeed. The perspective mapping, dynamic models, trajectory shape, and state-feedback controls are explained, and the results are presented graphically.

T.K.

#### A88-39622

THE CONTROLLED SYSTEM AS A SYSTEM WITH NONHOLONOMIC CONSTRAINTS - THE CASE OF A HELICOPTER [LE SYSTEME COMMANDE ET TANT QUE SYSTEME A LIAISONS NON HOLONOMES - CAS D'UN HELICOPTERE]

K. JANKOWSKI (Wyzsza Szkola Inzynierska, Radom, Poland) and J. MARYNIAK (Warszawa, Politechnika, Warsaw, Poland) Journal de Mecanique Theorique et Appliquee (ISSN 0750-7240), vol. 7, no. 2, 1988, p. 157-173. In French. refs

The motion of mechanical systems subjected to the constraints imposed by an automatic control system is investigated. A complete mathematical model of an automatically controlled helicopter is developed using the quasi-coordinate Boltzmann-Hamel equations for nonholonomic systems. The theory takes into account several degrees of freedom of the helicopter, which is treated as a rigid body. The problem of the presence of periodic coefficients is overcome by determining the angular coordinates of the main rotor and the tail rotor in a Fourier series, retaining only the first-order harmonics.

#### A88-40526#

STATUS AND TREND IN CCV

SABURO OGINO and TAKAO OSHIMA Japan Society for Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 35, no. 405, 1987, p. 460-467. In Japanese. refs

#### A88-40527#

**DEVELOPMENT OVERVIEW OF THE T-2 CCV** 

HIDEJIRO YAMADA, HIDEKI KANNO, AKIHIRO TAKEKOSHI, YUTAKA HINENO, and AKIO KATO Japan Society for Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 35, no. 405, 1987, p. 475-481. In Japanese.

#### A88-40528#

FBW SYSTEM AND CONTROL LAW OF THE T-2 CCV

MASAHIRO YASUE, AKIRA KUBO, TADASHI KAMEYAMA, MORIO TAKAHAMA, RYOJI KATAYANAGI et al. Japan Society for Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 35, no. 405, 1987, p. 482-492. In Japanese. refs

#### A88-40529#

FLIGHT TESTING RESULTS OF T-2 CCV

MASATO NAKAO, KATSUHEI SHIBATA, MASASHIRO IDE, YOSHIO ASANO, HIDEAKI OHMIYA et al. Japan Society for Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 35, no. 405, 1987, p. 492-500. In Japanese. refs

#### A88-40706\*#

THE EFFECTS OF CANARD-WING FLOW-FIELD INTERACTIONS ON LONGITUDINAL STABILITY, EFFECTIVE DIHEDRAL AND POTENTIAL DEEP-STALL TRIM

C. B. MUCHMORE, JR. IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 40-50. Research supported by the Joint Institute for the Advancement of Flight Sciences and NASA. refs

(AIAA PAPER 88-2514)

The literature available on high aspect ratio canard configurations shows them to have some unique stability characteristics. Using a generic canard-wing model, the effects of canard-wing flow-field interactions on stability were investigated in the NASA Langley Twelve-Foot Low-Speed Wind Tunnel. Results for the attached flow regime indicate linear interactions shift the neutral point of a canard configuration forward, but the effect of a canard on a wing can change significantly when the flow over the

surface begins to separate, even several degrees below stall. The asymmetry of the canard downwash in a sideslip condition can result in an increment in effective dihedral roughly proportional to canard lift coefficient. At very high angles of attack the presence of a wing can cause an incremental normal force on a canard, contributing to the possibility of a deep-stall trim point. This effect is greater for a high canard and less for a low one.

#### A88-40858#

DECENTRALIZED APPROACH TO THE DESIGN OF AUTOMATIC FLIGHT CONTROL SYSTEMS [DETSENTRALIZOVANI PRILAZ PROJEKTOVANJU AUTOMATSKOG SISTEMA UPRAVLJANJA LETOM]

M. VUKOBRATOVICH and R. STOJICH Srpska Akademija Nauka i Umetnosti, Glas, Odeljenje Tekhnichkikh Nauka, no. 25, 1988, p. 83-106. In Serbo-Croatian. refs

83-106. In Serbo-Croatian. refs

An approach to the decentralized control of large-scale nonlinear systems is applied to dynamic flight control. Control synthesis is performed in two steps: (1) the synthesis of the nominal, programmed control using the complete flight-dynamics model and (2) tracking of the nominal trajectory. A choice of subsystems is proposed for a particular case of flight control, and local and global control synthesis is proposed. A flight control simulation with the proposed control law is presented.

N88-22038# National Aerospace Lab., Amsterdam

(Netherlands).

DESIGN OF AN INTEGRATED CONTROL SYSTEM FOR FLUTTER MARGIN AUGMENTATION AND GUST LOAD ALLEVIATION, TESTED ON A DYNAMIC WINDTUNNEL MODEL

P. A. VANGELDER 12 May 1986 17 p Presented at the AIAA Guidance, Navigation and Control Conference, Williamsburg, Va., 18-20 Aug. 1986

(PB88-149885; NLR-MP-86034-U) Avail: NTIS HC A03/MF A01 CSCL 01C

The design method is described and some results are given from wind tunnel tests of a digitally implemented, integrated control system for both flutter augmentation and gust load alleviation. The control system was designed using optimization techniques applied to a reduced order output controller. Either the ailerons or the spoilers were used as control surfaces, while tailplanes and rudder were used additionally for rigid body mode control.

Author

N88-22039# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

APPLICATION OF EIGENSTRUCTURE ASSIGNMENT TECHNIQUES IN THE DESIGN OF A LONGITUDINAL FLIGHT CONTROL SYSTEM M.S. Thesis

DANIEL G. GODDARD Sep. 1987 121 p

(AD-A189644; AFIT/GAE/AA/87S-2) Avail: NTIS HC A06/MF A01 CSCL 01A

The use of eigenstructure assignment techniques has received wide attention as a tool for designing flight control systems for aircraft with multiple control surfaces. Development of a method for choosing the desired eigenstructure of the augmented, closed-loop system which would meet the handling qualities specifications was examined. This method consisted of forming an optimal plant matrix which possessed desirable dynamic characteristics and performing a spectral decomposition of this matrix. The resulting eigenstructure was used as the desired eigenvalues and eigenvectors during the full-state feedback, eigenstructure assignment process. The resulting feedback gain matrix was used in the control system. This process was performed on a model of the X-29A using the canard, flaperon, and strake flap control surfaces. The resulting augmented system was evaluated using the Neal-Smith pilot-model analysis and also using an X-29A man-in-the-loop simulation. The results show that the method is very promising, although care must be taken that all anticipated control system dynamics are considered when forming GRA the optimal A matrix.

N88-22040# Air Force Inst. of Tech., Wright-Patterson AFB. Ohio. School of Engineering.

MULTIVARIABLE CONTROL LAW DESIGN FOR THE AFTI/F-16 WITH A FAILED CONTROL SURFACE USING A PARAMETER-ADAPTIVE CONTROLLER M.S. Thesis

JULIO E. VELEZ Dec. 1987 183 p

(AD-A189848; AFIT/GE/ENG/87D-69) Avail: NTIS HC A09/MF CSCL 01D

Multivariable control laws are designed for the Advanced Fighter Technology Integration F-16 (AFTI/F-16). Both fixed gain and adaptive Proportional plus Integral (PI) controllers are designed for a plant were the number of outputs are not equal to the number of inputs (rectangular plant). Simulations are conducted for a healthy and a failed aircraft model. The failure consists of reducing the left elevator by 50 percent. When the fixed gain controller is used for the flight control system, the simulation reveals the fact that the aircraft failure causes the output responses to diverge. If provided with a persistently exciting input the adaptive controller prevents the aircraft failure simulation from diverging and going unstable. However, additional testing and/or tuning of the adaptive controller is required to determine and enhance the stability of the adaptive controller.

N88-22041# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

KALMAN FILTER RESIDUAL EXPERT SYSTEM M.S. Thesis JEFFREY D. GRIMSHAW Dec. 1987 189 p (AD-A190520; AFIT/GCE/ENG/87D-4) Avail: NTIS HC A09/MF

CSCL 12E

The Pilot's Associate (PA) program has been initiated to help mitigate the extensive workload of the fighter pilot. To operate effectively, the PA system must have situation awareness: the status of important on-board and off-board systems. This knowledge is gained through sensor systems. The data from these systems must be fused together to present the PA with a coherent picture of the internal (on-board) and external (off-board) states. Although many types of information can be extracted from sensor data, this paper emphasizes those parameters that help determine target track. One common technique for fusing sensor data uses Kalman filters. In a multiple model adaptive filter (MMAF) system, the most appropriate Kalman filter is chosen. This filter provides the best estimates of the desired states. An operating MMAF system continually selects which filter to use as the basis for the state estimates. The overall accuracy of the system is closely related to how well the filters are selected. Previous filter selection techniques have proved useful, but limited. To overcome some of these limitations, an expert system, KREST, was developed so that expert rules could be used to select filters.

N88-22042# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

SUBHARMONIC ALIASING AND ITS EFFECTS ON THE AFTI/F-16 DIGITAL FLIGHT CONTROL SYSTEM M.S. Thesis DAVID M. THOMAS Dec. 1987 114 p (AD-A190614; AFIT/GE/ENG/87D-66) Avail: NTIS HC A06/MF

CSCL 01D

The purpose of this research is threefold. First, determine the cause of subharmonic aliasing, described by the AFTI/F-16 engineers as the creation of uncorrelated low frequencies whenever a subharmonic of the sample frequency is input into the system. Second, model the subharmonic aliasing effect, so that, by knowing only input frequency and the system sample rate the output characteristics can be calculated. And third, demonstrate by simulation the effect of input and output filters on the subharmonic alias, and the effect of signals in the subharmonic range (omega(N)/10 less than omega(0) less than omega(S)/2) on the interchannel difference and the software rate limiter. The model determined that subharmonic aliasing is the result of imposter frequencies (much like aliasing) being introduced into the output signal by the sampling process. We defined subharmonic aliases occur due to: imposter frequencies and a phenomena known as apparent low frequency surge, which occurs when the input

frequency is nearly an integer multiple (greater than 1) of the imposter frequency.

#### N88-22903# European Space Agency, Paris (France). SERVO-ACTUATOR CONTROL FOR SAMPLED-DATA FEEDBACK DISTURBANCE REJECTION

JOSEF PETRY (Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Oberpfaffenhofen, West Germany) 221 p Transl. into ENGLISH of Zur Ansteuerung von Servoaktuatoren fuer die Stoergroessenkompensation mittels Abtastsystemen (Oberpfaffenhofen, Fed. Republic of Germany, DFVLR), Jan. 1986 199 p Original language document was announced as N88-32446

(ESA-TT-1002; DFVLR-FB-86-08; ETN-88-91974) Avail: NTIS HC A10/MF A01; original German version available from DFVLR. VB-PL-DO, 90 60 58, 5000 Cologne, Fed. Republic of Germany

Based on a helicopter it is demonstrated why discrete feedback control for disturbance rejection using a pulse-amplitude-modulated control signal can cause undesired disturbing effects. This analysis is done in the frequency domain by frequency, and by spectral decompositions of the signals concerned. The results provide recommendations for a controller design. A continuous minor-loop feedback control which allows the continuous plant to be appropriately adjusted to the characteristics of discrete disturbance rejection is proposed. The efficiency of this approach is confirmed by design examples and simulations.

N88-22904\*# Massachusetts Inst. of Tech., Cambridge. Lab. for Information and Decision Systems.

#### ANALYSIS AND DESIGN OF GAIN SCHEDULED CONTROL SYSTEMS Ph.D. Thesis

JEFF S. SHAMMA May 1988 203 p

(Contract NAG2-297)

(NASA-CR-182867; NAS 1.26:182867; LIDS-TH-1770) Avail:

NTIS HC A10/MF A01 CSCL 01C

Gain scheduling, as an idea, is to construct a global feedback control system for a time varying and/or nonlinear plant from a collection of local time invariant designs. However in the absence of a sound analysis, these designs come with no guarantees on the robustness, performance, or even nominal stability of the overall gain schedule design. Such an analysis is presented for three types of gain scheduling situations: (1) a linear parameter varying plant scheduling on its exogenous parameters, (2) a nonlinear plant scheduling on a prescribed reference trajectory, and (3) a nonlinear plant scheduling on the current plant output. Conditions are given which guarantee that the stability, robustness, and performance properties of the fixed operating point designs carry over to the global gain scheduled designs, such as the scheduling variable should vary slowly and capture the plants nonlinearities. Finally, an alternate design framework is proposed which removes the slowing varying restriction or gain scheduled systems. This framework addresses some fundamental feedback issues previously ignored in standard gain. Author

N88-22905\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

#### AN INVESTIGATION OF THE ABILITY TO RECOVER FROM TRANSIENTS FOLLOWING FAILURES FOR SINGLE-PILOT ROTORCRAFT

M. HOSSEIN MANSUR and JEFFERY A. SCHROEDER 1988 43 p

(NASA-TM-100078; A-88113; USAAVSCOM-TM-88-A-001; NAS 1.15:100078) Avail: NTIS HC A03/MF A01 CSCL 01C

A moving-base simulation was conducted to investigate a pilot's ability to recover from transients following single-axis hard-over failures of the flight-control system. The investigation was performed in conjunction with a host simulation that examined the influence of control modes on a single pilot's ability to perform various mission elements under high-workload conditions. The NASA Ames large-amplitude-motion Vertical Motion Simulator (VMS) was utilized, and the experimental variables were the failure axis, the severity of the failure, and the airspeed at which the

failure occurred. Other factors, such as pilot workload and terrain and obstacle proximity at the time of failure, were kept as constant as possible within the framework of the host simulation task scenarios. No explicit failure warnings were presented to the pilot. Data from the experiment are shown, and pilot ratings are compared with the proposed handling-qualities requirements for military rotorcraft. Results indicate that the current proposed failure transient requirements may need revision.

N88-22906# Air Force Wright Aeronautical Labs., Wright-Patterson AFB, Ohio.
STABILITY AND CONTROL METHODOLOGY FOR CONCEPTUAL AIRCRAFT DESIGN. VOLUME 1:
METHODOLOGY MANUAL Final Report, Jun. 1985 - Jun. 1987
TERRY S. SMITH Dec. 1987 179 p
(AD-A191314; AFWAL-TR-87-3115-VOL-1) Avail: NTIS HC A09/MF A01 CSCL 01A

This report contains methodology for predicting stability and control characteristics of conceptual flight vehicles. The methodology presented is a combination of existing methodology, modified existing methodology, and newly developed methodology. The methodology is divided into three main sections: (1) Aerodynamics of Longitudinal stability coefficients, (2) Lateral Stability coefficients, and (3) Static and Dynamic Stability Analysis.

# N88-23249\*# Georgia Inst. of Tech., Atlanta. APPLICATION OF NAVIER-STOKES ANALYSIS TO STALL FLUTTER

J. C. WU, R. SRIVASTAVA, and L. N. SANKAR In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 309-320 May 1988 (Contract NAG3-730)

Avail: NTIS HC A20/MF A01 CSCL 01A

A solution procedure was developed to investigate the two-dimensional, one- or two-dimensional flutter characteristics of arbitrary airfoils. This procedure requires a simultaneous integration in time of the solid and fluid equations of motion. The fluid equations of motion are the unsteady compressible Navier-Stokes equations, solved in a body-fitted moving coordinate system using an approximate factorization scheme. The solid equations of motion are integrated in time using an Euler implicit scheme. Flutter is said to occur if small disturbances imposed on the airfoil attitude lead to divergent oscillatory motions at subsequent times. The flutter characteristics of airfoils in subsonic speed at high angles of attack and airfoils in high subsonic and transonic speeds at low angles of attack are investigated. The stall flutter characteristics are also predicted using the same procedure.

# N88-23250\*# Toledo Univ., Ohio. A COMPUTATIONAL PROCEDURE FOR AUTOMATED FLUTTER ANALYSIS

DURBHA V. MURTHY In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 323-336 May 1988 Previously announced as N87-28058 Avail: NTIS HC A20/MF A01 CSCL 01A

A direct solution procedure for computing the flutter Mach number and the flutter frequency is applied to the aeroelastic analysis of propfans using an unsteady aerodynamic model based on a three-dimensional subsonic compressible lifting surface theory. An approximation to the Jacobian matrix that improves the efficiency of the iterative process is presented. The Jacobian matrix is indirectly approximated from approximate derivatives of the flutter matrix. Examples are used to illustrate the convergence properties. The direct solution procedure facilitates the automated flutter analysis in addition to contributing to the efficient use of computer time as well as the analyst's time.

#### 09

#### **RESEARCH AND SUPPORT FACILITIES (AIR)**

Includes airports, hangars and runways; aircraft repair and overhaul facilities; wind tunnels; shock tube facilities; and engine test blocks.

## A88-37182 LANDING SURFACE CHARACTERISTICS UNIQUE TO V/STOL AIRCRAFT

HAROLD FLUK (U.S. Naval Air Engineering Center, Lakehurst, NJ) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 87-99. refs (SAE PAPER 872310)

This article presents work performed at the Naval Air Engineering Center involving V/STOL Aircraft ground flows. Exhaust flows are directly related to aircraft size (thrust level) and propulsion system size (disk loading). A brief commentary on ground flow phenomena through the full range of disk loading is given. Major discussion is devoted to the narrower band of disk loading attendant with high performance V/STOL Aircraft. In particular, gas velocities and temperatures in the ground flow surroundings, and characteristics of pervasiveness are described. Heat transfer into a uniform structure has been calculated for concrete, poly/resin, asphalt, aluminum, and steel. Resultant surface and internal temperature distributions are shown. The influence of engine exhaust temperature, height above ground, and heating time is illustrated. Jet engine exhaust impingement tests of refractory concretes, asphalt, and aluminum have been conducted and compared with heat transfer computations. Material samples were subjected to afterburning gases at 3150 F and 2.5 atmospheres through prescribed heating and cool down cycles. Materials found capable of withstanding such high energy jets are described.

A88-37197\* National Aeronautics and Space Administration.
Ames Research Center, Moffett Field, Calif.
AERODYNAMIC FLOW QUALITY AND ACOUSTIC
CHARACTERISTICS OF THE 40- BY 80-FOOT TEST SECTION
CIRCUIT OF THE NATIONAL FULL-SCALE AERODYNAMIC

COMPLEX
LAWRENCE E. OLSON, PETER T. ZELL, PAUL T. SODERMAN, MICHAEL D. FALARSKI, VICTOR R. CORSIGLIA, and H. KIPLING EDENBOROUGH (NASA, Ames Research Center, Moffett Field, CA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 263-278. refs (SAE PAPER 872328)

The 40- by 80-foot wind tunnel circuit of the National Full-Scale Aerodynamic Complex (NFAC) has recently undergone major modifications and subsequently completed final acceptance testing. The initial testing and calibration of the wind tunnel are described and in many cases these results are compared with predictions derived from model tests and theoretical analyses. The wind tunnel meets or exceeds essentially all performance objectives. The facility runs smoothly and routinely at its maximum test-section velocity of 300 knots (Mach number = 0.45). An effective cooling air exchange system enables the wind tunnel to operate indefinitely at this maximum power condition. Throughout the operating envelope of the wind tunnel the test-section dynamic pressure is uniform to within + or - 0.5 deg, and the axial component of turbulence is generally less than 0.5 percent. Acoustic measurements indicate that, due to the low noise fans and acoustic treatment in the wind-tunnel circuit and test section, the background noise level in the test section is comparable to other large-scale acoustic wind tunnels in the United States and abroad. Author

#### A88-37298#

### LARGE-SCALE MODEL FOR EXPERIMENTAL WIND TUNNEL INVESTIGATIONS

PETER ESCH Dornier-Post (English Edition) (ISSN 0012-5563), no. 1, 1988, p. 59, 60.

A 1:4.2-scale model of the Do 328 commuter airliner having a wing span of 4.75 m has been constructed from aluminum by means of NC milling techniques in order to simulate the aerodynamic characteristics of the aircraft in all flight conditions with the highest degree of fidelity. In addition to attempting to achieve identical Reynolds numbers, an effort is made to duplicate engine thrust coefficient by using pneumatically-powered engines that drive the model's two tractor propellers. The resulting model flow allows careful determination of propeller wake influence on wing aerodynamics.

#### A88-37907

### AERODYNAMIC TESTING CONFERENCE, 15TH, SAN DIEGO, CA, MAY 18-20, 1988, TECHNICAL PAPERS

Conference sponsored by AIAA. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, 477 p. For individual items see A88-37908 to A88-37953.

The present conference on aerodynamic testing discusses European hypersonic testing technology, the coupling of CFD and wind tunnel test techniques, transition effects in dynamic simulation, hypersonic transition testing and prediction with magnetic suspension and balance systems, extreme altitude wind tunnel testing with magnetic suspension land balance systems, ballistic aerothermodynamic testing, Mach 10 skin friction measurement problems, and the aerodynamic lag of a close-coupled canard aircraft model at Mach 0.3-1.6. Also discussed are three-dimensional cavity flow at transonic speeds, adaptive-wall wind tunnel research with two- and three-dimensional models, flexible wind tunnel walls for supersonic flows, scale model acoustic testing of counterrotating fans, the control system for an injector-powered transonic wind tunnel, and challenges associated with very high Reynolds number testing.

#### A88-37909#

### A PLAN FÖR COUPLING WIND TUNNEL TESTING WITH CFD TECHNIQUES

S. WEINBERG, A. LAGANELLI, A. MARTELLUCCI (Science Applications International Corp., Wayne, PA), and K. KUSHMAN (USAF, Arnold Engineering Development Center, Arnold AFB, TN) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 12-21. refs (Contract F40600-85-C-0002) (AIAA PAPER 88-1996)

A plan for integrating computational fluid dynamics techniques with wind tunnel testing procedures to achieve enhanced test facility capabilities and productivity is presented and evaluated. The pretest, test and post-test elements of this WT/CFD coupling plan are identified, and the plan is applied to selected wind tunnel test programs in order to demonstrate and assess benefits. Significant advantages and cost savings are shown to result.

**A88-37910\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

### THE BASIC AERODYNAMICS RESEARCH TUNNEL - A FACILITY DEDICATED TO CODE VALIDATION

WILLIAM L. SELLERS, III and SCOTT O. KJELGAARD (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 22-33. refs (AIAA PAPER 88-1997)

Computational fluid dynamics code validation requirements are discussed together with the need for close interaction between experiment and code development. Code validation experiments require a great deal of data and for the experiments to be successful, a highly-productive research facility is required. A description is provided of the NASA Langley Basic Aerodynamics

Research Tunnel (BART); especially the instrumentation and experimental techniques that make the facility ideally suited to code validation experiments. Results are presented from recent tests which illustrate the techniques used in BART.

Author

A88-37911\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

# UNEXPECTED/EXPECTED RESULTS FROM THE LANGLEY 20-INCH SUPERSONIC WIND TUNNEL DURING INITIAL CHECKOUT

JAMES L. DILLON, FLOYD J. WILCOX, JR. (NASA, Langley Research Center, Hampton, VA), and ROBERT L. TRIMPI (George Washington University, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 34-42. (AIAA PAPER 88-1999)

NASA Langley's 20-Inch Supersonic Wind Tunnel is currently undergoing shakedown tests. The facility operates over the supersonic Mach number range of 1.4 to 5.0 with Reynolds number per foot variation of approximately 500,000 to 20 million. Checkout runs have been conducted at Mach numbers of 1.4, 2.8, and 5.0 over the entire operational mass flow and total pressure envelope. Data were recorded for total temperature characteristics, Rigimesh pressure drop characteristics, and for the switching exhaust system. Data recorded and observations made during checkout are discussed.

#### A88-37912#

### THE AEDC 1-FOOT TRANSONIC WIND TUNNEL - A USEFUL RESEARCH AND DEVELOPMENT FACILITY

R. L. PARKER, JR. and H. P. BLACK (Calspan Corp., Arnold AFB, TN) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 43-48. (AIAA PAPER 88-2001)

The USAF Arnold Engineering Development Center's 1-foot Aerodynamic Wind Tunnel is an inexpensively operated transonic wind tunnel for basic research in the Mach 0.2-1.5 range. This facility is noted to be extremely flexible in the matters of test section configuration and test installation, since it employs a three-dimensionally adaptive wall test section and variable-porosity walls. Its auxilliary systems, instrumentation capabilities, and computer facilities are comparable to larger and more sophisticated wind tunnels.

O.C.

#### A88-37913#

### DEVELOPMENT OF THE UNIVERSITY OF TEXAS AT ARLINGTON AERODYNAMICS RESEARCH CENTER

DONALD R. WILSON (Texas, University, Arlington) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 49-58. refs (AIAA PAPER 88-2002)

An account is given of the University of Texas' test facilities for research projects concerned with aerodynamics, aerothermodynamics, and aircraft propulsion, covering the spectrum from low to hypersonic speeds. A secondary goal of these facilities is the generation of experimental data bases supporting the development and validation of CFD codes. Specific laboratory facilities encompass the Low Speed Wind Tunnel Lab, the High Speed Aerodynamics Lab's High Reynolds Number Transonic Ludwieg-Tube Wind Tunnel and Supersonic Ludwieg Tube Wind Tunnel, the Hypersonic Shock Tunnel, and the Shock Tube Facility.

O.C.

#### A88-37914#

# OPTIMUM POROSITY FOR AN INCLINED-HOLE TRANSONIC TEST SECTION WALL TREATED FOR EDGETONE NOISE REDUCTION

G. M. ELFSTROM (DSMA International, Inc., Toronto, Canada), B. MEDVED (Vazduhoplovnotehnicki Institut, Belgrade, Yugoslavia), and W. J. RAINBIRD (Carleton University, Ottawa, Canada) IN:

Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988. Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 59-64. refs (AIAA PAPER 88-2003)

The aerodynamic wall interference properties of an inclined-hole porous wall are examined for the case where each hole has a splitter plate designed for edgetone noise attenuation. The degree of wall interference is ascertained by comparing measured cone/cylinder surface pressure signatures with those measured in the very low blockage tests carried out in the AEDC 16 ft wind tunnel, for a range of wall porosity settings, over a Mach number range of 0.6 to 1.4. In general, the present data show that low wall interference can be obtained. The optimum porosity settings are distinctly lower than those found for the AEDC 4 ft wind Author tunnel.

#### A88-37915#

#### REVIEW OF TRANSITION EFFECTS ON THE PROBLEM OF **DYNAMIC SIMULATION**

L. E. ERICSSON (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 65-85. refs

(AIAA PAPER 88-2004)

Among the many problems the test engineer faces when trying to simulate full scale vehicle dynamics in a wind tunnel test is the fact that the test usually will be performed at Reynolds numbers far below those existing on the full scale vehicle. It is found that even in the case of attached flow a severe scaling problem may exist. The strong coupling existing between boundary layer transition and vehicle motion can cause the wind tunnel results to be very misleading, in some cases dangerously so. For example, the subscale test can fail to show a dynamic stability problem existing in full scale flight, or, conversely, show one that does not exist on the full scale vehicle. When flow separation occurs together with boundary layer transition, the scaling problem becomes more complicated, and the potential for dangerously misleading subscale test results increases. The existing literature is reviewed to provide examples of the different types of dynamic simulation problems that the test engineer is likely to face. Author

#### A88-37916#

#### ON HYPERSONIC TRANSITION TESTING AND PREDICTION

KENNETH F. STETSON (USAF, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH), ELTON R. THOMPSON (USAF, Arnold Engineering Development Center, Arnold Air Force Station, TN), JOSEPH C. DONALDSON, and LEO G. SILER (Calspan Field Services, Inc., Arnold Air Force Station, TN) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 86-93. refs (AIAA PAPER 88-2007)

General aspects of the freestream environment and the dominant boundary-layer disturbances are discussed relative to their significance to boundary-layer transition. It is shown that the unique features of hypersonic boundary-layer transition introduce new environmental considerations for wind tunnel transition testing and transition prediction. Unlike the subsonic/supersonic situation, the boundary-layer disturbance mechanisms which influence transition of a hypersonic boundary-layer are not well known. Several potential disturbance mechanisms which could influence hypersonic transition are discussed and their possible implications regarding hypersonic transition wind tunnel testing and transition prediction. Boundary-layer stability experiments are considered essential for establishing the credibility of a hypersonic boundary-layer stability theory and the credibility of an analytical hypersonic transition prediction method. Author

A88-37917\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

A REVIEW OF MAGNETIC SUSPENSION AND BALANCE SYSTEMS

RICHMOND P. BOYDEN (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 94-105. refs (AIAA PAPER 88-2008)

This paper traces the development of Magnetic Suspension and Balance Systems (MSBSs) for use in wind tunnels. The expression MSBS implies a system that can both suspend a model and also measure the forces and moments acting on the model. This avoids the need for any mechanical support of the model. An MSBS uses electromagnets located outside the test section walls to create magnetic fields inside the test section. Measurement of the electrical current flowing in each of the electromagnets can be used to determine the forces and moments acting on the suspended model. An MSBS is capable of supporting a model with an internal magnetized core subject to gravity, aerodynamic, and inertial loads. The model must have a core made of either a permanent magnet, magnetized soft iron, or a solenoid. The position of the suspended body is inherently unstable. A closed-loop control system which includes a position sensing system has to control the position of the body by controlling the applied magnetic fields. This paper includes a discussion of all the known MSBSs and the outlook for larger systems.

A88-37918\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

#### DRAG MEASUREMENTS ON A BODY OF REVOLUTION IN LANGLEY'S 13-INCH MAGNETIC SUSPENSION AND **BALANCE SYSTEM**

DAVID A. DRESS (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 106-116. refs (AIAA PAPER 88-2010)

NASA Langley's 13-inch Magnetic Suspension and Balance System (MSBS) has been used to conduct low-speed wind tunnel drag force measurements on a laminar-flow body-of-revolution free of support system interference, in order to verify the drag force measurement capabilities of the MSBS. The drag force calibrations and wind-on repeatability data obtained have verified the design capabilities for this system. A drag-prediction code has been used to assess the MSBS's usefulness in body drag estimation.

#### A88-37920\*# Old Dominion Univ., Norfolk, Va. PROGRESS TOWARDS EXTREME ATTITUDE TESTING WITH MAGNETIC SUSPENSION AND BALANCE SYSTEMS

COLIN P. BRITCHER (Old Dominion University, Norfolk, VA) and DAVID H. PARKER IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 128-135. refs

(Contract NSG-7523; NAG1-716) (AIAA PAPER 88-2012)

Progress is reported in a research effort aimed towards demonstration of the feasibility of suspension and aerodynamic testing of models at high angles of attack in wind tunnel Magnetic Suspension and Balance Systems. Extensive modifications, described in this paper, have been made to the Southampton University suspension system in order to facilitate this work. They include revision of electromagnet configuration, installation of all-new position sensors and expansion of control system programs. An angle of attack range of 0 to 90 deg is expected for axisymmetric models. To date, suspension up to 80 deg angle of attack has been achieved.

A88-37921\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

#### A FORECAST OF NEW TEST CAPABILITIES USING MAGNETIC SUSPENSION AND BALANCE SYSTEMS

PIERCE L. LAWING and WILLIAM G. JOHNSON, JR. (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical

#### 09 RESEARCH AND SUPPORT FACILITIES (AIR)

Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 136-144. refs (AIAA PAPER 88-2013)

This paper outlines the potential of Magnetic Suspension and Balance System (MSBS) technology to solve existing problems related to support interference in wind tunnels. Improvement of existing test techniques and exciting new techniques are envisioned as a result of applying MSBS. These include improved data accuracy, dynamic stability testing, two-body/stores release testing, and pilot/designer-in-the-loop tests. It also discusses the use of MSBS for testing exotic configurations such as hybrid hypersonic vehicles. A new facility concept that combines features of ballistic tubes, magnetic suspension, and cryogenic tunnels is described.

Author

#### A88-37922#

### STUDY ON NEEDS FOR A MAGNETIC SUSPENSION SYSTEM OPERATING WITH A TRANSONIC WIND TUNNEL

W. R. MARTINDALE, R. W. BUTLER, and R. F. STARR, JR. (Sverdrup Technology, Inc., Arnold Air Force Station, TN) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 145-150. refs (AIAA PAPER 88-2014)

A survey of the U.S. aeronautical industry was conducted to determine if current and future transonic testing requirements are sufficient to justify continued development work on magnetic suspension and balance systems (MSBS) by NASA. The effort involved preparation of a brief technical description of magnetic balance and suspension systems, design of a survey form asking specific questions about the role of the MSBS in satisfying future testing requirements, selecting nine major aeronautical companies to which the description and survey forms were sent, and visiting the companies and discussing the survey to obtain greater insight to their response to the survey. An evaluation and discussion of the survey responses is presented.

# A88-37926\*# Syracuse Univ., N. Y. AN ISENTROPIC COMPRESSION HEATED LUDWIEG TUBE TRANSIENT WIND TUNNEL

PATRICK J. MAGARI and JOHN E. LAGRAFF (Syracuse University, NY) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 179-188. refs (Contract NAG3-621) (AIAA PAPER 88-2019)

Syracuse University's Ludwieg tube with isentropic compression facility is a transient wind tunnel employing a piston drive that incorporates insentropic compression heating of the test gas located ahead of a piston. The facility is well-suited for experimental investigations concerning supersonic and subsonic vehicles over a wide range of pressures, Reynolds numbers, and temperatures; all three parameters can be almost independently controlled. Work at the facility currently includes wake-induced stagnation point heat transfer and supersonic boundary layer transition.

O.C.

A88-37936\*# National Aeronautics and Space Administration. Langlev Research Center, Hampton, Va.

# A STUDY OF AEROELASTIC STABILITY FOR THE MODEL SUPPORT SYSTEM OF THE NATIONAL TRANSONIC FACILITY

THOMAS W. STRGANAC (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 305-310.

(AIAA PAPER 88-2033)

Oscillations of wind-tunnel models have been observed during testing in the National Transonic Facility. These oscillations have been the subject of an extensive investigation. As a part of this effort, a study of the aeroelastic stability of the model support structure has been performed. This structure is mathematically modelled as a wing and conventional flutter analysis is performed.

The math model implemented both experimentally and numerically obtained modal characteristics. A technique for illustrating the flutter boundary for wind tunnels is demonstrated. Results indicate that the classical flutter boundary is well above the operating envelope of the facility. However, the analysis indicates a damping-dependent instability is present which is inherent in the design. One possible modification in the design has been evaluated which eliminates the predicted instability.

A88-37938\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va. HIGHLIGHTS OF EXPERIENCE WITH A FLEXIBLE WALLED

TEST SECTION IN THE NASA LANGLEY 0.3-METER TRANSONIC CRYOGENIC TUNNEL

STEPHEN W. D. WOLF and EDWARD J. RAY (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 321-330. refs (AIAA PAPER 88-2036)

The unique combination of adaptive wall technology with a continuous flow cryogenic wind tunnel is described. This powerful combination allows wind tunnel users to carry out two-dimensional (2-D) tests at flight Reynolds numbers with wall interferences essentially eliminated. Validation testing was conducted to support this claim using well tested symmetrical and cambered airfoils at transonic speeds and high Reynolds numbers. The test section hardware has four solid walls, with the floor and ceiling flexible. The method of adapting/shaping the floor and ceiling to eliminate top and bottom wall interference at its source is outlined. Data comparisons for different size models tested and others in several sophisticated 2-D wind tunnels are made. In addition, the effects of Reynolds number, testing at high lift with associated large flexible wall movements, the uniqueness of the adapted wall shapes, and the effects of sidewall boundary layer control are examined. The 0.3-m TCT is now the most advanced 2-D research facility anywhere.

# A88-37939\*# Southampton Univ. (England). ADAPTIVE WALL RESEARCH WITH TWO- AND THREE-DIMENSIONAL MODELS IN LOW SPEED AND TRANSONIC TUNNELS

M. C. LEWIS, G. NEAL, and M. J. GOODYER (Southampton, University, England) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 331-341. Research supported by the Department of Trade and Industry and SERC. refs (Contract NSG-7172) (AIAA PAPER 88-2037)

This paper summarises recent research at the University of Southampton into adaptive wall technology and outlines the direction of current efforts. The work is aimed at developing techniques for use in test sections where the top and bottom walls may be adjusted in single curvature. Wall streamlining eliminates, as far as experimentally possible, the top and bottom wall interference in low speed and transonic aerofoil testing. A streamlining technique has been developed for low speeds which allows the testing of swept wing panels in low interference environments. At higher speeds, a comparison of several two-dimensional transonic streamlining algorithms has been made and a technique for streamlining with a choked test section has also been developed. Three-dimensional work has mainly concentrated on tests of sidewall mounted half-wings and the development of the software packages required to assess interference and to adjust the flexible walls. It has been demonstrated that two-dimensional wall adaptation can significantly modify the level of wall interference around relatively large three-dimensional models. The residual interferences are small and are probably amenable to standard post-test correction methods. Tests on a calibrated wing-body model are planned in the near future to further validate the proposed streamlining technique.

**Author** 

#### A88-37940#

# TWO-DIMENSIONAL AND THREE-DIMENSIONAL ADAPTATION AT THE T2 TRANSONIC WIND TUNNEL OF ONERA/CERT

J. P. ARCHAMBAUD and A. MIGNOSI (ONERA, Centre d'Etudes et de Recherches de Toulouse, France) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 342-350. refs (AIAA PAPER 88-2038)

The T2 transonic wind tunnel is one of the few facilities in the world working in cryogenic range (Ts=110 K - Max Reynolds number 30 M) with adaptive wall technique. The wind tunnel operates for research and production type activities since 1983. Firstly, this paper describes the T2 test section with its 2D top and bottom flexible walls and the displacement mechanism. Then, main features of the 2D adaptation strategy are explained, and results on airfoils are presented. Finally, the 3D adaptation strategy is developed and test results with symmetrical bodies and half wings are presented.

## A88-37941# ADAPTATION OF FLEXIBLE WIND TUNNEL WALLS FOR SUPERSONIC FLOWS

S. L. RILL and U. GANZER (Berlin, Technische Universitaet, Federal Republic of Germany) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 351-356. BMFT-sponsored research. (AIAA PAPER 88-2039)

Adaptive walls are supposed to reduce or possibly eliminate wall interferences in wind tunnels. A recent topic of research in the field of adaptive wall technique at TU-Berlin has been the extension of the adaptation procedure to flows at high subsonic and low supersonic Mach numbers. In this paper a detailed description of the concept of supersonic wall adaptation together with first experimental results obtained in the octagonal test section is presented. A numerical simulation of the supersonic adaptation is used to study the convergence behavior and the influence of the jack spacing on the residual interferences.

#### ARR-37942#

### THE RESEARCH ON ADAPTIVE WALL WIND TUNNEL IN NORTHWESTERN POLYTECHNICAL UNIVERSITY OF CHINA

JIA JU HE and PEI CHU ZUO (Northwestern Polytechnical University, Xian, People's Republic of China) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 357-362. refs (AIAA PAPER 88-2040)

An evaluation is made of the last five years' progress with adaptive wall test section-incorporating wind tunnel designs in a major Chinese research facility, at the Northwestern Polytechnical University of China. Attention is given to the working principles of two adaptive-wall wind tunnel types investigated, the numerical simulation of such wind tunnels, the design of a flexible-wall self-streamlining test section, and the results of a program of iterative testing involving a method for convergent velocity acceleration.

#### A88-37943#

### THE USE OF 2-D ADAPTIVE WALL TEST SECTIONS FOR 3-D FLOWS

E. WEDEMEYER (DFVLR, Goettingen, Federal Republic of Germany) and L. LAMARCHE (Montreal, Universite, Montreal, Canada) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 363-371. refs (AIAA PAPER 88-2041)

A method for the use of adaptive wall wind tunnel test sections with two flexible walls for the testing of three-dimensional models, first proposed by Wedemeyer in 1982, has been elaborated and verified by means of both numerical and experimental tests.

Attention is presently given to the results of the application of a linear and a nonlinear adaptation procedure, as revealed by numerical and experimental trials. For a typical aircraft wind tunnel model in a square test section with 70-percent span/tunnel width ratio, the wall-induced upwash at the wing tips is reduced to 25 percent of its original value. The wall adaptation procedure is simple and requires little computational effort so long as the wall equations can be linearized.

# A88-37944\*# Sandia National Labs., Albuquerque, N. Mex. HEATING REQUIREMENTS AND NONADIABATIC SURFACE EFFECTS FOR A MODEL IN THE NTF CRYOGENIC WIND TUNNEL

J. M. MACHA, D. B. LANDRUM (Sandia National Laboratories, Albuquerque, NM), L. A. PARE, III (Lockheed Missiles and Space Co., Inc., Sunnyvale, CA), and C. B. JOHNSON (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 372-381. refs (Contract NAG1-417)

(AIAA PAPER 88-2044) A theoretical study has been made of the severity of nonadiabatic surface conditions arising from internal heat sources within a model in a cryogenic wind tunnel. Local surface heating is recognized as having an effect on the development of the boundary layer, which can introduce changes in the flow about the model and affect the wind tunnel data. The geometry was based on the NTF Pathfinder I wind tunnel model. A finite element heat transfer computer code was developed and used to compute the steady state temperature distribution within the body of the model, from which the surface temperature distribution was extracted. Particular three dimensional characteristics of the model were represented with various axisymmetric approximations of the geometry. This analysis identified regions on the surface of the model susceptible to surface heating and the magnitude of the respective surface temperatures. It was found that severe surface heating may occur in particular instances, but could be alleviated with adequate insulating material. The heat flux through the surface of the model was integrated to determine the net heat required to maintain the instrumentation cavity at the prescribed temperature. The influence of the nonadiabatic condition on boundary layer properties and on the validity of the wind tunnel simulation was also investigated.

A88-37945\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

### A FLOW-TRANSFER DEVICE WITH NONMETALLIC DIAPHRAGMS FOR PROPULSION WIND TUNNEL MODELS

FRANCIS J. CAPONE and BARRY L. PRICE (NASA, Langley Research Center, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 382-391. refs

(AIAA PAPER 88-2048)

The Langley Research Center has developed a new flow-transfer device for powered wind tunnel models in which the traditional metal bellows have been replaced with nonmetallic diaphragms. Two complete flow transfer assemblies have been fabricated and installed within a twin-jet propulsion simulation system. Calibrations of the force balance have been performed over a range of nozzle mass flow rates up to 15 lbs/sec in order to validate the nonmetallic diaphragm design concept. Results from these calibrations are compared to those obtained with flow-transfer devices utilizing metal bellows.

#### A88-37946#

#### MACH NUMBER CORRECTIONS FOR A TWO-FOOT PROPELLER RIG IN SOLID AND SLOTTED TEST SECTIONS

A. J. KRYNYTZKY (Boeing Commercial Airplane Co., Seattle, WA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American

Institute of Aeronautics and Astronautics, 1988, p. 392-401. refs (AIAA PAPER 88-2056)

A 2-ft diameter contrarotating propfan of a type under consideration for noise-critical commercial aircraft applications has been wind tunnel tested in both acoustic (solid-walled) and slotted test sections at Mach of up to 0.83. A combination of experimental and theoretical techniques is used to develop a flight-equivalent test Mach number, including corrections for solid blockage, support interference, and thrust interference. The use of wall-mounted static pressure rails is noted to be indispensable in correlating Mach number in the two test sections.

O.C.

# A88-37949# MICROPROCESSOR CONTROL OF HIGH-SPEED WIND TUNNEL STAGNATION PRESSURE

Y.-T. FUNG, G. S. SETTLES, and A. RAY (Pennsylvania State University, University Park) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 429-435. refs (Contract AF-AFOSR-84-0184)

(Contract AF-AFOSH-84-01 (AIAA PAPER 88-2062)

The development and implementation of a control algorithm for the microprocessor-based stagnation pressure control system of the Penn State Supersonic Wind Tunnel Facility is reported. The gas dynamics and the control-valve characteristics of this blowdown-type facility are nonlinearly related. A mathematical model was developed for the open-loop system characteristics and was linearized for the controller design. A single-input, single-output PI controller was chosen for this task because of its simplicity and availability. The resulting performance of the supersonic wind tunnel was found to be quite good, with stagnation pressure variations typically held to within 1 to 2 percent. Author

#### A88-37950#

### DEVELOPMENT OF A CONTROL SYSTEM FOR AN INJECTOR POWERED TRANSONIC WIND TUNNEL

D. F. LONG and K. S. GLADEN (Fluidyne Engineering Corp., Minneapolis, MN) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 436-445. refs

(AIAA PAPER 88-2063)

A mathematical model of the FFA T1500 Injector Driven Transonic Wind Tunnel is developed. The tunnel process is simulated by solving the equations of one-dimensional gas dynamics. These are modified where appropriate to simulate the operation of the injector, circuit exhaust, test section plenum and the choke control system downstream of the test section. The algorithms which control the valve actuation rates are described. Results are presented which show that the control system is able to stabilize the tunnel flow and that the startup time from rest to stable flow is on the order of four seconds.

#### A88-38169

# WIND TUNNEL INTERFERENCE ON UNSTEADY TWO-DIMENSIONAL AEROFOIL MOTIONS IN LOW SPEED FLOWS

C. W. CHEUNG and G. J. HANCOCK (Queen Mary College, London, England) Aeronautical Journal (ISSN 0001-9240), vol. 92, March 1988, p. 115-121.

The aerodynamic characteristics of two-dimensional transient aerofoil motions in low-speed flows in a wind tunnel with either closed wall or open (jet) walls, including the effect of a downstream closed wall diffuser, have been investigated. The mathematical formulation for the aerofoil and its unsteady wake is based on linear theory and is solved by a piecewise linear vorticity method; the wall boundaries are represented by distributions of sources. Numerical calculations have been made for various values of tunnel height to chord ratio. Interference effects on the rate of build up of lift to a steady state following a step change in incidence can be large, especially for open jet tunnels.

**A88-38692\***# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

USE OF DYNAMICALLY SCALED MODELS FOR STUDIES OF THE HIGH-ANGLE-OF-ATTACK BEHAVIOR OF AIRPLANES

JOSEPH R. CHAMBERS (NASA, Langley Research Center, Hampton, VA) International Symposium on Scale Modeling, Tokyo, Japan, July 18-22, 1988, Paper. 11 p. refs

Dynamically scaled, free-flying models are used by NASA to study the stalling and spinning characteristics of civil and military airplane configurations. Such tests have been conducted for many different designs, and it has been possible to correlate the results predicted by the model tests with flight test results obtained in the investigations. The present paper describes four of the dynamic model testing techniques used at the NASA Langley Research Center, including the scaling laws used in the construction of models and in the interpretation of results. Predictions of stall/spin behavior based on model results have generally been very accurate, and the model tests are regarded as an invaluable precursor to full-scale flight tests. However, aerodynamic scale effects between some models and full-scale airplanes due to differences in test values of Reynolds number have resulted in erroneous predictions for a few configurations. A discussion of these effects is provided, together with the approach used to modify the model so that its behavior more closely matches that of the airplane. Finally, two typical applications of the techniques to the X-29A research airplane and several general aviation research airplanes are presented to illustrate the type of information provided by the tests.

A88-38711\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

### THE NASA INTEGRATED TEST FACILITY AND ITS IMPACT ON FLIGHT RESEARCH

D. A. MACKALL, M. D. PICKETT, L. J. SCHILLING, and C. A. WAGNER (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 85-97. refs (AIAA PAPER 88-2095)

NASA-Ames' Integrated Test Facility (ITF), when completed, will provide ground test facilities for the safe and efficient testing of advanced research aircraft with fully integrated flight control, propulsion systems, structures, and aerodynamic configurations. Flight test risk will be minimized through the reduction of differences between flight and ground test environments; the latter will involve the interfacing of real-time flight simulation with the actual aircraft through a simulation-interface device. The test process and the collection and management of test data will be automated. Attention is given to preliminary ITF results for the X-29 aircraft.

A88-38712\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

DEVELOPMENT OF AN INTEGRATED SET OF RESEARCH FACILITIES FOR THE SUPPORT OF RESEARCH FLIGHT TEST ARCHIE L. MOORE and CONSTANCE D. HARNEY (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 98-111. refs (AIAA PAPER 88-2096)

The Ames-Dryden Flight Research Facility (DFRF) serves as the site for the conduct of high-risk flight research on many one-of-a-kind test vehicles like the X-29A advanced technology demonstrator, F-16 advanced fighter technology integration (AFTI), AFTI F-111 mission adaptive wing, and F-18 high-alpha research vehicle (HARV). Ames-Dryden is on a section of the historic Muroc Range. The facility is oriented toward the testing of high-performance aircraft, as shown by its part in the development of the X-series aircraft. Given the cost of research flight test and the complexity of today's systems-driven aircraft, an integrated set of ground support experimental facilities is a necessity. In support of the research flight test of highly advanced test beds, the DFRF is developing a network of facilities to expedite the acquisition and distribution of flight research data to the researcher.

This network consists of an array of experimental ground-based facilities and systems as nodes and the necessary telecommunications paths to pass research data and information between these facilities. This paper presents a status of the current network, an overview of current developments, and a prospectus on future major enhancements.

#### A88-38713#

#### USING GPS TO ENHANCE THE DT&E RANGES

THOMAS P. HANCOCK (USAF, Washington, DC) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 112-117.

(AIAA PAPER 88-2098)

GPS flight test range instrumentation will yield very precise target position indications, allow mobile land/sea ranges to be established without presurvey, extend existing ranges over their current horizons, and establish a world-wide common grid system facilitating interrange operations. Attention is presently given to the characteristics of the data link and range system, the solid state recorder employed, the translator-translator processor concept and design, the treatment of ground transmitters as 'pseudosatellites', and the results of efforts to integrate each of the demonstration ranges.

#### A88-38740#

### FLIGHT TESTING AT THE WEST COAST OFFSHORE OPERATING AREA

DALE A. DOTY, STANLEY K. GAROUTTE, and ERNIE R. SNOWDON (ITT Federal Electric Corp., Vandenberg AFB, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 343-350.

(AIAA PAPER 88-2150)

The USAF's West Coast Offshore Operating Area (WCOOA) stretches off the California coast from Point Conception in the south to 44 deg N. In addition to possessing overlapping coverage from Air Route Surveillance Radars, users can make use of both the Western Test Range and U.S. Navy Pacific Missile Test Center. Under normal weather conditions, flights are conducted in a virtually isothermal environment. Favorable conditions exist for hazardous activities throughout WCOOA, due to the empty ocean over which flights are conducted.

A88-38744\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

# DEVELOPMENT OF AN INTERACTIVE REAL-TIME GRAPHICS SYSTEM FOR THE DISPLAY OF VEHICLE SPACE POSITIONING

ROBERT COMPERINI (Datamax Computer Systems, Inc., Edwards, CA) and DONALD C. RHEA (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 376-387. (AIAA PAPER 88-2167)

This paper will outline a new approach taken by the NASA Western Aeronautical Test Range to display real-time space positioning data using computer-generated images that produce a graphic representation of an area map integrated with the research flight test aircraft track. This display system supports research flight test requirements of research projects such as the advanced fighter technology integration (AFTI) F-16, F-18 high alpha research vehicle (HARV), AFTI F-111 mission adaptive wing (MAW), F-15, and X-29A forward-swept wing. This paper will discuss the requirements, system configuration and capability, and future system applications.

A88-38745\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

THE PC/AT COMPATIBLE COMPUTER AS A MISSION CONTROL CENTER DISPLAY PROCESSOR AT AMES-DRYDEN FLIGHT RESEARCH FACILITY

KEVIN R. HAMMONS (NASA, Flight Research Center, Edwards,

CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 388-405. refs (AIAA PAPER 88-2168)

The NASA Ames-Dryden Flight Research Facility's Western Aeronautical Test Range will assign the flight test data display processing function to Mission Control Centers in order to allow research engineers to flexibly configure their own display-processing system to optimize performance during a flight research mission. This will leave the Telemetry Radar Acquisition and Processing System more time to acquire data. One of the processors chosen to handle the display-processing function is an IBM PC/AT-compatible, rack-mounted PC giving engineers a personalized set of analytic and display tools, developed on the basis of off-the-shelf PC/AT-compatible engineering hardware and software items.

A88-38761\*# National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif.

### DEVELOPMENT OF A MOBILE RESEARCH FLIGHT TEST SUPPORT CAPABILITY

DONALD C. RHEA and ARCHIE L. MOORE (NASA, Flight Research Center, Edwards, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 520-528. (AIAA PAPER 88-2087)

This paper presents the approach taken by the NASA Western Aeronautical Test Range (WATR) of the Ames Research Center (ARC) to develop and utilize mobile systems to satisfy unique real-time research flight test requirements of research projects such as the advanced fighter technology integration (AFTI) F-16, YAV-8B Harrier, F-18 high-alpha research vehicle (HARV), XV-15, and the UH-60 Black Hawk. The approach taken is cost-effective, staff efficient, technologically current, and provides a safe and effective research flight test environment to support a highly complex set of real-time requirements including the areas of tracking and data acquisition, communications (audio and video) and real-time processing and display, postmission processing, and command uplink. The development of this capability has been in response to the need for rapid deployment at varied site locations with full real-time comutation and display capability. This paper will discuss the requirements, implementation and growth plan for mobile systems development within the NASA Western Aeronautical Test Range. Author

#### A88-39525#

# THE INTEGRATION OF WIND TUNNEL AND WATER TUNNEL RESULTS FOR A NEW IN-FLIGHT SIMULATOR CONFIGURATION

DENNIS L. CARTER (USAF, Flight Dynamics Laboratory, Wright-Patterson AFB, OH) AIAA, Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988. 13 p. (AIAA PAPER 88-2045)

A series of wind tunnel and water tunnel tests have been conducted to study the generation of direct sideforce for the VISTA (Variable Stability In-Flight Simulator Test Aircraft). The studies involved low-speed wind tunnel and water tunnel tests of vertical fins mounted on the wing of an F-16 aircraft at various span stations. Results showed that the vortex coming from the strake can be utilized to generate significant levels of direct sideforce over most of the usable angle of attack range.

#### A88-40066

#### VEHICLES AND AIRCRAFT ON FLOATING ICE

V. A. SQUIRE, P. J. LANGHORNE (Otago, University, Dunedin, New Zealand), W. H. ROBINSON, and T. G. HASKELL (Department of Scientific and Industrial Research, Lower Hutt, New Zealand) Nature (ISSN 0028-0836), vol. 333, May 12, 1988, p. 159-161. Research supported by the New Zealand Ross Dependency Research Committee, University of Cambridge, Royal Society of London, and Trans-Antarctic Association.

Some preliminary results are reported from a new and complete

set of experiments done on Antarctic sea ice using strain gages to measure directly the strain induced in the ice by vehicles driving over it. The experimental vehicles were an extended cab pickup truck weighing 2100 kg and an LC-130 Hercules aircraft weighing some 50,000 kg. The results show excellent agreement in all respects with theoretical calculations of the deflection profile due to moving loads.

# A88-40721\*# Vigyan Research Associates, Inc., Hampton, Va. A PANEL METHOD PROCEDURE FOR INTERFERENCE ASSESSMENT IN SLOTTED-WALL WIND TUNNELS

WILLIAM B. KEMP, JR. (Vigyan Research Associates, Inc., Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 185-193. refs

(Contract NAS1-17919; NASA TASK 32) (AIAA PAPER 88-2537)

This paper describes a method for three-dimensional wind tunnel interference assessment developed specifically for slotted-wall tunnels. The method is an adaptation to the assessment problem of a previously published high-order panel method procedure for simulating the flow in slotted-wall tunnel test sections. The method uses a mixed outer boundary condition, primarily a Neumann condition, with measured pressure constraints used to control only those boundary phenomena which can not be specified accurately a priori. Assessment results are illustrated from a calibration test with variations in wall geometry, and from tests of a generic subsonic transport aircraft configuration.

**A88-40722\***# National Aeronautics and Space Administration. Langlev Research Center, Hampton, Va.

### A TRANSONIC WIND TUNNEL WALL INTERFERENCE PREDICTION CODE

PAMELA S. PHILLIPS and EDGAR G. WAGGONER (NASA, Langley Research Center, Hampton, VA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 194-203. refs (AIAA PAPER 88-2538)

A small disturbance transonic wall interference prediction code has been developed that is capable of modeling solid, open, perforated, and slotted walls as well as slotted and solid walls with viscous effects. This code was developed by modifying the outer boundary conditions of an existing aerodynamic wing-body-pod-pylon-winglet analysis code. The boundary conditions are presented in the form of equations which simulate the flow at the wall, as well as finite difference approximations to the equations. Comparisons are presented at transonic flow conditions between computational results and experimental data for a wing alone in a solid wall wind tunnel and wing-body configurations in both slotted and solid wind tunnels.

A88-40723\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif. DIRECT ASSESSMENT OF TWO-DIMENSIONAL

### WIND-TUNNEL INTERFERENCE FROM MEASUREMENTS ON TWO INTERFACES

CHING F. LO (NASA, Ames Research Center, Moffett Field, CA) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 204-207. refs (AIAA PAPER 88-2539)

A direct assessment of two-dimensional wind-tunnel wall interference using upwash component measured on two interfaces has been formulated by the Prandtl-Glauert equation of the flow field and solved by the Fourier transform technique. The analytic formulae obtained for the interference of upwash and pressure on the model are presented. The formulae have been applied successfully to the analytic models for lifting and blockage interferences induced by the general linear slotted and perforated tunnel wall boundary conditions. The formulae have been derived

in terms of Fourier coefficients of the measured upwash and illustrated its merits applying to a wavy-wall model case. Author

N88-22043# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

### GEOMETRIC MODELING OF FLIGHT INFORMATION FOR GRAPHICAL COCKPIT DISPLAY M.S. Thesis

MARK A. KANKO Dec. 1987 120 p Original contains color illustrations

(AD-A190484; AFIT/GCE/ENG/87D-6) Avail: NTIS HC A06/MF A01 CSCL 01D

The purpose of this thesis was to design and implement a graphics-based environment capable of modeling tactical situation arenas as viewed from the cockpit. The modeled region was composed of mountains, hostile threat envelopes, and a projected flightpath through the region. Resulting displays were to be used in the Microprocessor-Based Application of Graphics Interactive Communication (MAGIC) cockpit owned by the Crew Systems Development Branch within the USAF FDL at Wright-Patterson. This cockpit is used to prototype new graphical display formats that might be used in future aircraft. The individual 3-D objects used to represent threats and mountains in the model were generated by geometric procedural models. A strongly-parameterized procedural model would generate a three-dimensional surface of revolution composed of polygons from a 2-D profile input by the user. Once defined, each object could then be instantiated into the model representing the complete tactical situation. Positioning of objects in the model was accomplished via a mouse input device. The implemented data representation allowed the model to be easily modifiable. An overall goal was to allow the cockpit display researcher to create an entirely new tactical situation display model in less than one hour.

N88-22044# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

### MULTIPLE MODEL PARAMETER ADAPTIVE CONTROL FOR IN-FLIGHT SIMULATION M.S. Thesis

THOMAS J. BERENS Mar. 1988 88 p

(AD-A190568; AFIT/GE/ENG/88M-3) Avail: NTIS HC A05/MF A01 CSCL 01D

Adaptive control of aircraft model-following systems has shown promising results for in-flight simulation, but the computational expense and slow convergence of conventional parameter estimation techniques for higher order models inhibits their direct use for in-flight simulation. Computer simulations of adaptive systems usually assume some knowledge of model parameters in order to maintain tracking fidelity at a reasonable computational cost as parameters change. This thesis incorporates apriori information into a multiple-model estimation algorithm which assigns a probability weighting of each estimator within a bank of estimators. Final parameter estimates used in adaptive control are formed as a probabalistic weighted sum of individual estimates. Simulations of the system show excellent tracking performance throughout the flight envelope. A moving bank scheme for use over a wide range of flight conditions is recommended as a further area of study.

N88-22045\*# Stanford Univ., Calif. Joint Inst. for Aeronautics and Acoustics.

### CONTRACTION DESIGN FOR SMALL LOW-SPEED WIND TUNNELS

JAMES H. BELL and RABINDRA D. MEHTA Apr. 1988 37 p (Contract NCC2-294)

(NASA-CR-182747; NAS 1.26:182747; JIAA-TR-84) Avail: NTIS HC A03/MF A01 CSCL 14B

An iterative design procedure was developed for 2- or 3-dimensional contractions installed on small, low speed wind tunnels. The procedure consists of first computing the potential flow field and hence the pressure distributions along the walls of a contraction of given size and shape using a 3-dimensional numerical panel method. The pressure or velocity distributions are then fed into 2-dimensional boundary layer codes to predict the

behavior of the boundary layers along the walls. For small, low speed contractions, it is shown that the assumption of a laminar boundary layer originating from stagnation conditions at the contraction entry and remaining laminar throughout passage through the successful designs is justified. This hypothesis was confirmed by comparing the predicted boundary layer data at the contraction exit with measured data in existing wind tunnels. The measured boundary layer momentum thicknesses at the exit of four existing contractions, two of which were 3-D, were found to lie within 10 percent of the predicted values, with the predicted values generally lower. From the contraction wall shapes investigated, the one based on a 5th order polynomial was selected for newly designed mixing wind tunnel installation.

#### N88-22046# Oak Ridge National Lab., Tenn. INVESTIGATION OF AEROACOUSTIC MECHANISMS BY REMOTE THERMAL IMAGING

A. J. WITTEN and G. E. COURVILLE 1988 15 p Presented at the 10th Thermosense Conference, Orlando, Fla., 4 Apr. 1988 (Contract DE-AC05-84OR-21400)

(DE88-002612; CONF-880461-1) Avail: NTIS HC A03/MF A01 A hush house is a hangar-like structure designed to isolate, from the surrounding environment, the noise produced by extended aircraft engine operations during testing. While hush houses meet this intended need by suppressing audible noise, they do emit significant subaudible acoustic energy causing structural vibrations in nearby facilities. As a first step in mitigating the problems associated with hush house induced vibrations, it is necessary to identify the mechanism responsible for the low frequency acoustic emissions. It was hypothesized that the low frequency acoustic waves are a result of acoustic Cherenkov radiation. This radiation is in the form of a coherent wave produced by the engine exhaust gas flow. The speed of sound in the exhaust gas is quite high as a result of its elevated temperature. Therefore, the gas flow is sonic or subsonic relative to its own sound speed, but is supersonic relative to sound speed in the surrounding cooler air and, as a result, produces acoustic Cherenkov radiation. To confirm this hypothesis, thermographic surveys were conducted to image the thermal structure of the engine exhaust gas within the hush house. In the near field, these images revealed that the exhaust gases did not behave like a high Reynolds number turbulent jet, but rather, the transition to turbulence is delayed by a suppression in growth of the self-excited instability wave as a result of acoustic Cherenkov radiation.

National Aeronautics and Space Administration. N88-22047\*# Langley Research Center, Hampton, Va.

#### MODIFICATIONS TO THE LANGLEY 8-FOOT TRANSONIC PRESSURE TUNNEL FOR THE LAMINAR FLOW CONTROL **EXPERIMENT**

CHARLES D. HARRIS and CUYLER W. BROOKS, JR. May 1988 123 p

(NASA-TM-4032; L-16387; NAS 1.15:4032) Avail: NTIS HC A06/MF A01 CSCL 14B

Modifications to the NASA Langley 8 Foot Transonic Pressure Tunnel in support of the Lamina Flow Control (LFC) Experiment included the installation of a honeymoon and five screens in the settling chamber upstream of the test section 41-long test section liner that extended from the upstream end of the test section contraction region, through the best section, and into the diffuser. The honeycomb and screens were installed as permanent additions to the facility, and the liner was a temporary addition to be removed at the conclusion of the LFC Experiment. These modifications are briefly described.

National Bureau of Standards, Boulder, Colo. N88-22048# Electromagnetic Fields Div.

EMR (ELECTROMAGNETIC RADIATION) TEST FACILITIES **EVALUATION OF REVERBERATING CHAMBER LOCATED AT** RADC (ROME AIR DEVELOPMENT CENTER), GRIFFISS AFB (AIR FORCE BASE), ROME, NEW YORK

M. L. CRAWFORD, G. H. KOEPKE, and J. M. LADBURY

1987 78 p Sponsored by RADC, Griffiss AFB, N.Y. (PB88-178827; NBSIR-87/3080) Avail: NTIS HC A05/MF A01 CSCL 14B

The report describes measurement procedures and results obtained from evaluating the reverberating chamber facility located at the Rome Air Development Center (RADC), Griffiss Air Force Base, Rome, New York. The facility was developed by the RADC for use in measuring and analyzing the electromagnetic susceptibility/vulnerability (EMS/V) of weapon systems and the shielding effectiveness of enclosures and shielding materials. A brief description of the facility, including the instrumentation used for performing its evaluation and calibration by the National Bureau of Standards (NBS) is given.

National Telecommunications and Information N88-22049# Administration, Boulder, Colo. Inst. for Telecommunication Sciences.

#### INVESTIGATIONS OF TEST METHODOLOGY FOR THE STRESS LOADING FACILITY

188 p Sep. 1987 Sponsored by Army R. D. JENNINGS Electronic Proving Ground, Fort Huachuca, Ariz. (PB88-166095; NTIA-87-228) Avail: NTIS HC A09/MF A01 CSCL 14B

The U.S. Army Electronic Proving Ground (USAEPG) is planning the development of a new test facility to be known as the Stress Loading Facility (SLF). The facility is envisioned as an integrated and automated test capability that will generate a dense electromagnetic threat test environment and simultaneously monitor key performance parameters of a system being tested. The report reviews current test capabilities that are relevant to the SLF, both within and outside of USAEPG, and develops test methodologies ĞRA for the SLF.

National Aeronautics and Space Administration. N88-22050\*# Ames Research Center, Moffett Field, Calif.

### REAL-TIME FLIGHT TEST DATA DISTRIBUTION AND

MICHAEL C. NESEL and KEVIN R. HAMMONS May 1988 11 Presented at the 4th Flight Test Conference, San Diego, Calif., 18-20 May 1988

(NASA-TM-100424; H-1454; NAS 1.15:100424; REPT-314-50; REPT-314-60; AIAA-88-2216) Avail: NTIS HC A03/MF A01 CSCL 14B

Enhancements to the real-time processing and display systems of the NASA Western Aeronautical Test Range are described. Display processing has been moved out of the telemetry and radar acquisition processing systems super-minicomputers into user/client interactive graphic workstations. Real-time data is provided to the workstations by way of Ethernet. Future enhancement plans include use of fiber optic cable to replace the Ethernet.

#### N88-22907# Sandia National Labs., Albuquerque, N. Mex. ULTRASONIC TIME-OF-FLIGHT DIFFRACTION (TOFD) MEASUREMENTS OF CRACK DEPTHS IN AN ACCELERATION RESERVOIR OF A HIGH VELOCITY RESEARCH GUN

J. H. GIESKE 1988 17 p Presented at the 30th Meeting of the Weapons Agencies Nondestructive Testing Organization (WANTO), Largo, Fla., 12 Jan. 1988 (Contract DE-AC04-76DP-00789)

(DE88-006644; SAND-88-0376C; CONF-880160-4) Avail: NTIS

HC A03/MF A01

The Acceleration Reservoir (AR) of a two-stage light gas gun at Sandia's STAR - Shockwave Thermodynamic Applied Research - facility allows for the formation of shock fronts to propagate and accelerate projectiles with impact velocities up to 25,000 ft/second. The shock loading techniques are used by the Thermomechanical and Physical Division 1534 to study the properties of materials under extreme stress, stress rate, and temperature conditions. Because of the impact of a lead slurry-impregnated polyethylene piston at the tapered section of the AR, fatigue cracks develop and propagate in the bore area after each shot of the gun. Presently, the AR is taken out of service when the outer diameter of the AR increases by a given amount. In order to learn more about the actual damage present in a retired AR, the present study was undertaken. The reservoir investigated in this study was taken out of service after 103 shots. The ultrasonic pulse echo and Time-Of-Flight Diffraction (TOFD) techniques were employed in order to quantify the distribution of cracks along with their lengths and depths. The ultrasonic data will be used by division 1534 to investigate the nature of the fracturing process and perhaps model with a computer the dynamics of a crack subjected to pulse and shock loading. Hopefully, this information may then be used in the future to determine the proper retirement time of the reservoir.

N88-22909# Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Brunswick (West Germany). Hauptabteilung Windkandele.

# THE TRANSONIC WIND TUNNEL (TWB) AT DFVLR, BRUNSWICK (FEDERAL REPUBLIC OF GERMANY) Status Report, 1987

WOLFGANG PUFFERT-MEISSNER Dec. 1987 47 p In GERMAN; ENGLISH summary Report will also be announced as translation (ESA-TT-1114) Original contains color illustrations (DFVLR-MITT-88-01; ISSN-0176-7739; ETN-88-92317) Avail: NTIS HC A03/MF A01; DFVLR, VB-PL-DO, 90 60 58, 5000 Cologne, Fed. Republic of Germany, 30.50 DM

The transonic wind tunnel Braunschweig is a pressurized blowdown windtunnel. The test section for two-dimensional airfoil testing has an area of 0.34 x 0.60 m. Mach number range is from 0.3 to 0.95 and Reynolds number range from 2,900,000 to 12 million at Mach 0.7, based on an airfoil chord length of 150 mm. Information required for the preliminary planning of test programs and for preliminary layout of models used in such programs is given.

 $\textbf{N88-22911}^{\bullet}\#$  National Aeronautics and Space Administration, Washington, D.C.

FLOW QUALITY OF NAL TWO-DIMENSIONAL TRANSONIC WIND TUNNEL. PART 1: MACH NUMBER DISTRIBUTIONS, FLOW ANGULARITIES AND PRELIMINARY STUDY OF SIDE WALL BOUNDARY LAYER SUCTION

SEIZO SAKAKIBARA, KAZUAKI TAKASHIMA, HITOSHI MIWA, YASUO OGUNI, MAMORU SATO, and HIROSHI KANDA May 1988 96 p Transl. into ENGLISH of Japanese report (Tokyo, Japan, National Aerospace Lab.), 1982 p 1-79 Original language document was announced as N83-12043 Transl. by Scientific Translation Service, Santa Barbara, Calif. (Contract NASW-4307)

(NASA-TT-20209; NAS 1.77:20209; NAL-TR-693) Avail: NTIS HC A05/MF A01 CSCL 14B

Experimental data on the flow quality of the National Aerospace Laboratory two-dimensional transonic wind tunnel are presented. Mach number distributions on the test section axis show good uniformity which is characterized by the two sigma (standard deviation) values of 0.0003 to 0.001 for a range of Mach numbers from 0.4 to 1.0. Flow angularities, which were measured by using a wing model with a symmetrical cross section, remained within 0.04 deg for Mach numbers from 0.2 to 0.8. Side wall boundary layer suction was applied through a pair of porous plates. The variation of aerodynamic properties of the model due to the suction mass flow rate change is presented with a brief discussion. Two dimensionality of the flow over the wing span is expected to be improved by applying the appropriate suction rate, which depends on the Mach number, Reynolds number, and lift coefficient.

Author

N88-22912# Universal Energy Systems, Inc., Dayton, Ohio. SOFT-GROUND AIRCRAFT ARRESTING SYSTEMS Final Report, Sep. 1986 - Aug. 1987

ROBERT F. COOK Aug. 1987 142 p (Contract F33615-86-D-3800)

(AD-A190838; DOT/FAA/PM-87/27) Avail: NTIS HC A07/MF A01 CSCL 01E

The soft-ground aircraft arresting system study was initiated

to determine whether or not aircraft having gross weight of 114,000 pounds to 630,000 pounds could be safely stopped after overrunning the available length of runway. The extended length of runway was limited to 1000 feet and the maximum velocity of the overrunning aircraft was selected to be 70 knots. The system was to be completely passive, have a long life, and easily repaired and maintained. Several arrestor materials such as clay, sand. gravel, water, an plastic foam were considered. An aircraft wheel/arrestor material model was developed and incorporated into a computer program FITER which allowed the determination of the aircraft stopping distance, landing gear loads, dynamic response, and rut depth in the arrestor material. Analyses conducted showed that sand, clay and water systems were not suitable arresting materials. Aircraft arrestment simulations were conducted for gravel and plastic foam arrestors and it was found that all aircraft could be safely stopped in less than 1000 feet. Evaluation of the stopping distance in an arrestor bed with the stopping distance of an extended runway was made and it was found that the arrestor system was needed to assure the safe stopping of an aircraft. GRA

N88-23126\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

### WATER FACILITIES IN RETROSPECT AND PROSPECT: AN ILLUMINATING TOOL FOR VEHICLE DESIGN

GARY E. ERICKSON, DAVID J. PEAKE, JOHN DELFRATE, ANDREW M. SKOW, and GERALD N. MALCOLM (Eidetics International, Inc., Torrance, Calif.) *In* AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 28 p Jun. 1987 Previously announced as N87-13403

Avail: NTIS HC A20/MF A01 CSCL 14B

Water facilities play a fundamental role in the design of air, ground, and marine vehicles by providing a qualitative, and sometimes quantitative, description of complex flow phenomena. Water tunnels, channels, and tow tanks used as flow-diagnostic tools have experienced a renaissance in recent years in response to the increased complexity of designs suitable for advanced technology vehicles. These vehicles are frequently characterized by large regions of steady and unsteady 3-D flow separation and ensuing vortical flows. The visualization and interpretation of the complicated fluid motions about isolated vehicle components and complete configurations in a time and cost effective manner in hydrodynamic test facilities is a key element in the development of flow control concepts, and, hence, improved vehicle designs. A historical perspective of the role of water facilities in the vehicle design process is presented. The application of water facilities to specific aerodynamic and hydrodynamic flow problems is discussed, and the strengths and limitations of these important experimental tools are emphasized.

# N88-23128# Societe Bertin et Cie, Plaisir (France). QUALIFICATION OF A WATER TUNNEL FOR FORCE MEASUREMENTS ON AERONAUTICAL MODELS [QUALIFICATION DUN TUNNEL HYDRODYNAMIQUE POUR DES PESEES DE MAQUETTES AERONAUTIQUES]

B. CHEZLEPRETRE and Y. BROCARD In AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 15 p Jun. 1987 In FRENCH; ENGLISH summary Avail: NTIS HC A20/MF A01

Bertin and Company maintains a water tunnel where flow visualization, and velocity and force measurements are performed. Recently, force measurements were done on a wing-canard model which was also tested in a wind tunnel at ONERA. This paper focuses on the presentation of the facility (including its laser anemometer and the computerized data acquisition system) and on the satisfactory comparison of the balance measurements obtained in both water and wind tunnels.

N88-23132# National Research Council of Canada, Ottawa (Ontario). Low Speed Aerodynamics Lab.
THE USE OF THE NRC/NAE WATER FACILITIES IN

CANADIAN AERONAUTICAL RESEARCH AND DEVELOPMENT R. H. WICKENS and N. E. JEFFREYS /n AGARD, Aerodynamic

and Related Hydrodynamic Studies Using Water Facilities 20 p

Avail: NTIS HC A20/MF A01

Described are some of the hydrodynamic facilities of the National Research Council in Ottawa and St. John's, Newfoundland. The NAE water tunnel, in particular, contributed to the understanding of the aerodynamics of various VSTOL concepts, and complex flows containing strong elements of vorticity and unsteadiness. Several projects are described in which fundamental flow observations were made, and from which data was obtained in support of theoretical investigations. The past and future potential of several water facilities of the NRC for pursuing aeronautical and marine research are described.

#### 10

#### **ASTRONAUTICS**

Includes astronautics (general); astrodynamics; ground support systems and facilities (space); launch vehicles and space vehicles; space transportation; spacecraft communications, command and tracking; spacecraft design, testing and performance; spacecraft instrumentation; and spacecraft propulsion and power.

#### A88-39419#

**TECHNOLOGIES FOR HYPERSONIC FLIGHT** 

ECKART STEINHEIL and WOLFGANG UHSE Dornier-Post (English Edition) (ISSN 0012-5563), no. 2, 1988, p. 45-48.

An account is given of the technology readiness requirements of the West German Saenger II air-breathing first-stage, two-stage reusable launcher system. The present, five-year conceptual development phase will give attention to propulsion, aerothermodynamic, materials/structures, and flight guidance technology development requirements. The second, seven-year development phase will involve other West European design establishments and lead to the construction of a demonstration vehicle. Attention is presently given to the air-breathing propulsion system, and to flight-weight structural systems under consideration for both external heating and internal cryogenic tankage requirements.

A88-41288\* National Aeronautics and Space Administration, Washington, D.C.

NATIONAL AERO-SPACE PLANE

WILLIAM M. PILAND (NASA, Arlington, VA) IN: Visions of tomorrow: A focus on national space transportation issues; Proceedings of the Twenty-fifth Goddard Memorial Symposium, Greenbelt, MD, Mar. 18-20, 1987. San Diego, CA, Univelt, Inc., 1987, p. 219-222.

(AAS PAPER 87-127)

An account is given of the technology development management objectives thus far planned for the DOD/NASA National Aero-Space Plane (NASP). The technology required by NASP will first be developed in ground-based facilities and then integrated during the design and construction of the X-30 experimental aircraft. Five airframe and three powerplant manufacturers are currently engaged in an 18-month effort encompassing design studies and tradeoff analyses. The first flight of the X-30 is scheduled for early 1993.

11

#### **CHEMISTRY AND MATERIALS**

Includes chemistry and materials (general); composite materials; inorganic and physical chemistry; metallic materials; nonmetallic materials; and propellants and fuels.

#### A88-37429#

#### KRYPTONITE THEY ARE NOT

BRUCE FRISCH Aerospace America (ISSN 0740-722X), vol. 26, May 1988, p. 16-18, 20, 26.

The thin but increasingly complex coatings that are needed to protect superalloys from hot combustion gases in modern jet engines are discussed. The historical development of these coatings is reviewed, and the methods of depositing the coatings are described, emphasizing the electron beam method. Cost aspects are considered, and the role of automation in the application of the coatings is addressed.

#### A88-37430#

#### GAS TURBINES CHALLENGE CERAMIC TECHNOLOGY

DAVE CARRUTHERS and JIM WIMMER (Allied-Signal Aerospace Co., Arlington, VA) Aerospace America (ISSN 0740-722X), vol. 26, May 1988, p. 22-24, 26.

The design of practical ceramics for gas turbine engines is discussed. The ceramic design process in this application is described, indicating the tasks necessary to achieve conceptualization, optimization, experimentation, and validation. The development of this design approach to more complex gas turbine engine systems over time is reviewed. Future developments in this area of ceramics science are briefly considered.

#### A88-38315

#### **CORROSION-RESISTANT THERMAL BARRIER COATINGS**

WING-FONG CHU and F. J. ROHR (Brown Boveri et Cie. AG, Heidelberg, Federal Republic of Germany) Advanced Ceramic Materials (ISSN 0883-5551), vol. 3, May 1988, p. 222-224. BMFT-supported research. refs

Results of an experimental study of the corrosion resistance of zirconia-based thermal barrier coatings to combustion products, such as vanadates and sulfates generated in fuel-fired gas turbines, are reported. With reference to results obtained for the system ZrO2-Y2O3-SiO2-Al2O3, it is shown that it is possible to enhance the corrosion resistance of ZrO2-based thermal barrier coatings by the addition of Al2O3 and SiO2. The addition of these oxides leads to the enveloping of ZrO2(Y2O3) crystallites by zirconium and aluminum silicates, which are formed during sintering and precipitate preferentially on the ZrO2(Y2O3) grain boundaries.

V.L.

#### A88-38316

### IMPROVING THE RELIABILITY OF SILICON NITRIDE - A

JEFFREY T. NEIL, ARVID E. PASTO, and LESLIE J. BOWEN (GTE Laboratories, Inc., Waltham, MA) Advanced Ceramic Materials (ISSN 0883-5551), vol. 3, May 1988, p. 225-230. refs

Recent AGT engine test data indicate that, in prototype quantities, structural ceramics can be made capable of meeting the stringent mechanical constraints imposed by the turbine environment. Questions remain to be answered about the long-term capabilities of structural ceramics and their reliability in production quantities. The reliability of structural ceramics can be enhanced in three ways: by careful processing, improving fracture toughness using composites, and by appropriate NDE/proof-testing. Data generated by research in all three areas suggest that none of these alone is a panacea for the reliability problem. However, taken in combination, these data suggest that the necessary levels of reliability can be attained even in production ceramic turbine rotors. Research results on GTE AY6 sintered Si3N4 are presented to support this viewpoint.

#### A88-38490

## DEVELOPMENT OF A VARIATIONAL METHOD FOR CHEMICAL KINETIC SENSITIVITY ANALYSIS

D. GROUSET, P. PILON, E. ZNATY (Societe Bertin et Cie., Tarnos, France), and S. GALANT (Societe Bertin et Cie., Les Milles, France) IN: Symposium (International) on Combustion, 21st, Munich, Federal Republic of Germany, Aug. 3-8, 1986, Proceedings. Pittsburgh, PA, Combustion Institute, 1988, p. 795-806; Discussion, p. 806, 807. DRET-supported research. refs

A novel method of variational sensitivity analysis is applied to the kinetics of aircraft engine combustors and validated by comparisons with the 'brute force' method for hydrogen-oxygen combustion in a stirred reactor assembly. The variational method is shown to require far less computational time; the method is also applied to complete kinetic schemes for methanol/oxygen and ethane/air combustion in a reactor assembly. The results obtained with reduced schemes for methanol, involving 11 reactions among the 88 original ones, appear satisfactory.

#### A88-39417#

### MODERN SURFACE PROTECTIONS FOR AIRCRAFT

REINHOLD HOLBEIN Dornier-Post (English Edition) (ISSN 0012-5563), no. 2, 1988, p. 34-36.

The 20-year service life typical of aircraft generates demanding surface protection criteria against corrosion and such other possible forms of environmentally induced damage as erosion, temperature variations, and tribological action. Attention is presently given to the battery of fundamental properties, laboratory media, open-air weathering, and combined-load component tests, as well as flight tests, that must be conducted. The Dacromet 500 metalorganic coating is found to yield a good profile of results, even after 16 months of exposure to a marine atmosphere.

O.C.

#### A88-40174

# EFFECT OF LOAD DURATION ON THE FATIGUE BEHAVIOUR OF GRAPHITE/EPOXY LAMINATES CONTAINING DELAMINATIONS

D. S. SAUNDERS and T. J. VAN BLARICUM (Department of Defence, Aeronautical Research Laboratories, Melbourne, Australia) Composites (ISSN 0010-4361), vol. 19, May 1988, p. 217-228.

At high sustained loads it is known that creep-rupture can occur in short periods of time or contribute damage to carbon fiber composite components. This paper investigates the effect of load holds on the fatigue performance of impact damaged carbon fiber composite coupons by using two modified versions of a loading spectrum, static failure tests and application of sustained static loading, and examines damage growth together with coupon stiffness during fatigue testing. Stiffness degradation, shown to be associated with delamination growth, could be used to predict coupon failure.

#### A88-40486

### ELEVATED-TEMPERATURE AL ALLOYS FOR AIRCRAFT STRUCTURE

RICHARD A. RAINEN and JOHN C. EKVALL (Lockheed Aeronautical Systems Co., Sunland, CA) Journal of Metals (ISSN 0148-6608), vol. 40, May 1988, p. 16-18. refs

Elevated-temperature powder metallurgy (P/M) aluminum alloys are being developed to replace titanium aircraft structure materials for operation in the 300-600 F temperature range. Typical mechanical properties of P/M Al-Fe-Ce and Al-Fe-V-Si alloys are superior to those of conventional materials, and cost savings of 50 to 70 percent have been projected for these alloys which can be fabricated and processed using methods similar to those used in the production of conventional aluminum.

Author

N88-22092# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

A STUDY OF DAMAGE TOLERANCE IN CURVED COMPOSITE PANELS M.S. Thesis

BRENDAN L. WILDER Mar. 1988 152 p

(AD-A190617; AFIT/GA/AA/88M-3) Avail: NTIS HC A08/MF A01 CSCL 11D

As more and more composite materials are used in modern aircraft construction, the understanding of the damage tolerance of this relatively stiff, brittle, anisotropic material becomes important to designers. The behavior of a cylindrical composite panel made of AS4/3501-6 graphite/epoxy with ply orientations is investigated. Abrasion and burn surface damage was physically modeled in the panels. The panels were then tested by compressively loading them and a comparison was made to buckling predictions obtained. These tests indicated that panels which have suffered minor surface damage do not deviate significantly from buckling predictions. Composite laminates subjected to a low speed impact, such as a dropped tool or a manufacturing load, often develop an internal delamination. Since curved panels are 3-dimensional, and buckling is a non-linear phenomenon, the compressive load which will cause curved panels to become unstable is extremely hard to predict analytically. A technique whereby the local buckling loads at the delamination may be predicted using a 2-D model with a plane strain correction is presented.

N88-22115# Stanford Univ., Calif. High Temperature Gasdynamics Lab.

### TURBULENT REACTING FLOWS AND SUPERSONIC

COMBUSTION Annual Report, 15 Sep. 1986 - 30 Sep. 1987 C. T. BOWMAN, R. K. HANSON, M. G. MUNGAL, and W. C. REYNOLDS 30 Sep. 1987 28 p Original contains color illustrations

(Contract F49620-86-K-0022)

(AD-A189690; AFOSR-87-1899TR) Avail: NTIS HC A03/MF A01 CSCL 21B

An experimental and computational investigation of supersonic combustion flows is in progress. The principal objective of the research is to gain a more fundamental understanding of mixing and chemical reaction in supersonic flows. The research effort comprises three inter-related elements: (1) an experimental study of mixing and combustion in a supersonic plane mixing layer; (2) development of laser-induced fluorescence techniques time-resolved two-dimensional imaging of species concentration, temperature, velocity and pressure; and, (3) numerical simulations of compressible reacting flows. The design of the supersonic plane mixing layer was completed and the high-pressure gas storage system was installed. The pulsed lasers and camera systems, to be used for two-dimensional flow field imaging, were installed and initial performance evaluations are in progress. This work has focussed on development of appropriate numerical methods for performing full-turbulence simulations of high-speed compressible flows and on the application of these methods to temporally and spatially developing compressible mixing layers. The effort to date identified several promising numerical methods compressible flow problems. In addition, a code was developed for compressible mixing layers, and initial simulation using this code shows interesting features, such as imbedded shock waves, in high-speed mixing layers.

# N88-22121# California Inst. of Tech., Pasadena. INVESTIGATION OF COMBUSTION IN LARGE VORTICES Annual Technical Report, Sep. 1986 - Sep. 1987 FRANK E. MARBLE 12 Oct. 1987 22 p

(Contract AF AFOSR-0286-84)

(AD-A190406) Avail: NTIS HC A03/MF A01 CSCL 21B

The investigations of non-steady and unstable combustion in a dump combustor have been completed. The large amplitude driving mechanism centers on the periodic formation and combustion of a large vortex, the phase of heat release being governed by both gas dynamic and chemical delay times. This mechanism is now very well understood, both in principle and in quantitative detail. These results make it a prime candidate for investigations into active control of unstable combustion. The unsteady combustion facility is now being modified to study the details of combustion processes in large vortices utilizing a CID image intensified camera and an LDV for velocity measurements in the hot gas. This study

constitutes an essential element in a larger study of shock enhancement for combustion of hydrogen in supersonic burners.

N88-22405\*# Sverdrup Technology, Inc., Cleveland, Ohio. STRUCTURAL ANALYSES OF ENGINE WALL COOLING CONCEPTS AND MATERIALS

ALBERT KAUFMAN In NASA. Lewis Research Center, Lewis Structures Technology, 1988. Volume 2: Structural Mechanics p 265-280 May 1988

Avail: NTIS HC A14/MF A01 CSCL 11D

The severe thermal environments under which hypersonic aircraft such as the National Aerospace Plane (NASP) will operate require cooling of the engine walls, especially in the combustor. A preliminary assessment is made of some candidate materials based on structural analyses for a number of convective cooling configurations. Three materials were studied: graphite/copper and tungsten/copper composite alloys with 50 percent fiber volume fractions and a wrought cobalt-base superalloy, Haynes 188. Anisotropic mechanical and thermal properties for the composites were obtained from a computer code, ICAN, which determines the composite material properties from the individual properties of the fiber and matrix materials. The structural analyses were performed by using the MARC nonlinear finite element code. Heat transfer analyses were conducted to calculate the metal Author temperature distributions.

N88-22427\*# Pratt and Whitney Aircraft, East Hartford, Conn. FATIGUE DAMAGE MODELING FOR COATED SINGLE CRYSTAL SUPERALLOYS

DAVID M. NISSLEY In NASA. Lewis Research Center, Lewis Structures Technology, 1988. Volume 3: Structural Integrity Fatigue and Fracture Wind Turbines HOST p 259-270 May 1988 (Contract NAS3-23939)

Avail: NTIS HC A16/MF A01 CSCL 11F

A high temperature, low-cycle fatigue life prediction method for coated single crystal nickel-base superalloys is being developed. The method is being developed for use in predicting crack initiation life of coated single crystal turbine airfoils. Although the models are being developed using coated single crystal PWA 1480, they should be readily adaptable to other coated nickel-base single crystal materials. The coatings choosen for this effort were of two generic types: a low pressure plasma sprayed NiCoCrAIY overlay, designated PWA 286, and an aluminide diffusion, designated PWA 273. In order to predict the useful crack initiation life of airfoils, the constitutive and failure behavior of the coating/substrate combination must be taken into account. Coatings alter the airfoil surface microstructure and are a primary source from which cracks originate. The adopted life prediction approach addresses this complexity by separating the coating and single crystal crack initiation regimes. This provides a flexible means for using different life model formulations for the coating and single crystal materials. At the completion of this program, all constitutive and life model formulations will be available in equation form and as software. The software will use the MARC general purpose finite element code to drive the constitutive models and calculate life Author parameters.

N88-22940# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.
A STUDY OF FAILURE CHARACTERISTICS IN THERMOPLASTIC COMPOSITE MATERIAL M.S. Thesis

ROBERT J. MARTIN Mar. 1988 236 p (AD-A190613; AFIT/GA/AA/88M-2) Avail: NTIS HC A11/MF

A01 CSCL 11D

The recently introduced thermoplastic composite material, graphite polyetherether-ketone (Gr/PEEK) APC-2, promises lower costs, lower part weight, and higher operating temperatures. This new class of organic material has fracture toughness properties superior to those of graphite epoxy. This thesis examines the failure characteristics of Gr/PEEK through an experimental investigation and through the application of a fully nonlinear ply-by-ply finite element technique. The experimental investigation

of Gr/PEEK APC-2 involved the testing of 34 tension and compression coupons to derive basic material properties for use with the finite element program. This investigation provided further data on the application of tensile loads to Gr/PEEK containing circular discontinuities. This study also proved that a nonlinear finite element program can closely approximate progressive ply failure in a Gr/PEEK laminate. This research reinforced the proposition that the thermoplastic matrix does produce a reliable composite that should be considered for use on aircraft, spacecraft, and space facilities.

N88-22949\*# National Aeronautics and Space Administration.
Langley Research Center, Hampton, Va.

TOWARDS A DAMAGE TOLERANCE PHILOSOPHY FOR COMPOSITE MATERIALS AND STRUCTURES

T. KEVIN OBRIEN (Army Aerostructures Directorate, Hampton, Va.) Mar. 1988 63 p (Contract DA PROJ. 1L1-61102-AH-45-C) (NASA-TM-100548; USAAVSCOM-TM-88-B-009; NAS

1.15:100548) Avail: NTIS HC A04/MF A01 CSCL 11D

A damage-threshold/fail-safe approach is proposed to ensure that composite structures are both sufficiently durable for economy of operation, as well as adequately fail-safe or damage tolerant for flight safety. Matrix cracks are assumed to exist throughout the off-axis plies. Delamination onset is predicted using a strain energy release rate characterization. Delamination growth is accounted for in one of three ways: either analytically, using delamination growth laws in conjunction with strain energy release rate analyses incorporating delamination resistance curves; experimentally, using measured stiffness loss; or conservatively, assuming delamination onset corresponds to catastrophic delamination growth. Fail-safety is assessed by accounting for the accumulation of delaminations through the thickness. A tension fatigue life prediction for composite laminates is presented as a case study to illustrate how this approach may be implemented. Suggestions are made for applying the damage-threshold/fail-safe approach to compression fatigue, tension/compression fatigue, and compression strength following low velocity impact.

N88-22954# McDonnell Aircraft Co., St. Louis, Mo. NONDESTRUCTIVE EVALUATION OF LARGE SCALE COMPOSITE COMPONENTS Final Report, 25 Sep. 1984 - 31 Mar. 1987

DANIEL C. KING, R. D. LAWSON, and B. J. ROMINE Jan. 1988

(Contract F33615-84-C-5017)

(AD-A190998; AFWAL-TR-87-4116) Avail: NTIS HC A04/MF A01 CSCL 11D

This report covers the development of a reciprocating time-of-flight ultrasonic inspection system capable of rapid scanning of large area composite structures. Representative aircraft composite structures with flaw inclusions were fabricated to evaluate the effects of scanner design, coupling characteristics, part curvature, near and far surface defect detection, imaging, and data acquisition and storage capabilities. The results were used to combine a mechanical scanner, software, and electronics equipment into a working breadboard system. Breadboard evaluation results indicate that a downsized portable system is a viable inspection tool, and produces production quality ultrasonic C-scan images at comparable production scanning rates.

N88-22989 Joint Publications Research Service, Arlington, Va. MODEL STUDY OF THERMAL STRESSES IN GAS-TURBINE BLADES WITH PROTECTIVE COATING Abstract Only

G. N. TRETYACHENKO, K. P. BUYSKIKH, L. V. KRAVCHUK, and G. R. SEMENOV In its JPRS Report: Science and Technology. USSR: Materials Science p 4 17 Mar. 1988 Transl. into ENGLISH from Problemy Prochnosti (Kiev, USSR), no. 5, May 1987 p 67-70

Avail: Issuing Activity

A model study of thermal stresses in gas turbine blades with protective coating was made, such blades being simulated by nine different wedges of the ZhS6U heat resistant alloy. Wedges of

different sizes and chords were coated by electron beam method with Ni-Co-Cr-Al-Y, Ni-Cr-Al-Y, and Co-Cr-Al-Y alloys. For comparison, one wedge of each size was not coated. These wedges were tested under a heat load simulation. The test results based on measurement of surface temperature indicate that a proper coating can increase the asymmetry of the thermal load cycle with a shift of stresses more into the compressive range while lowering their amplitude so that such a coating will not only protect blades against corrosion and erosion but also raise their mechanical load capacity.

Author

N88-22990 Joint Publications Research Service, Arlington, Va. DEPENDENCE OF STRUCTURE OF STABILIZED ZRO2 COATINGS ON CONDENSATION RATE Abstract Only

A. M. MARTIROSYAN, V. V. GRABIN, N. I. GRECHANYUK, I. YA. DZYKOVICH, A. A. TROFIMENKO, and A. L. SAMSONOV In its JPRS Report: Science and Technology. USSR: Materials Science p 4-5 17 Mar. 1988 Transl. into ENGLISH from Problemy Spetsialnoy Elektrometallurgii (Kiev, USSR), no. 2, Apr. - Jun. 1987 p 47-51

Avail: Issuing Activity

An experimental study of ZrO2 coatings stabilized with Y2O3 for gas turbine blades was made, its purpose being to find the causes for their high thermal shielding capability as well as their proneness to peeling off the heat resistant steel. The coating material was produced by mixing powders of pure ZrO2 and high purity Y2O3 in a 23:2 ratio and then pressing the mixture. These rods were coated by means of electron beam under a vacuum with an 8 percent Y2O3 stabilizer. These specimens were then heat treated. The bond strength was measured by counting the number of thermal cycles withstood. Microstructural exams with x-radiographic analyses quantitative and microhardness measurements revealed formation of two layers. Coatings produced by condensation at a rate of 0.56 micron/min withstood more than 20 thermal cycles, those produced by condensation at a rate of 1.52 micron/min broke down after one or two cycles.

Author

N88-22998# Brown, Boveri und Cie, A.G., Mannheim (West Germany). Zentrales Labor fuer Werkstofftechnik.

EVALUATION OF CERAMIC THERMAL BARRIER COATINGS FOR GAS TURBINE ENGINE COMPONENTS European Concerted Action.COST 501-D28Final Report, Jan. 1983 -Dec. 1985

RALF BUERGEL, KLAYS SCHNEIDER, and BEATE TRUECK Aug. 1986 53 p

(ETN-88-91947) Avail: NTIS HC A04/MF A01

Duplex thermal barrier systems were assessed under test conditions relevant for stationary gas turbines including thermal cycling, cyclic oxidation, and hot corrosion. Attention is focused on ZrO2 -7/8 wt percent Y2O3 ceramic systems that prove to be most durable for turbine applications. The test results reveal that thermal barrier systems are available which are sufficiently thermal cyclic resistant. Oxidation of the metallic bond coat is identified as the life-limiting process while hot corrosion is less of a problem at high temperatures (950 C or above). An approach to overcome early degradation of the bond coat is to apply layers with few processing defects, i.e., to replace air plasma spraying of metallic coats by vacuum chamber spraying or inert gas shroud spraying wherever it is technically feasible.

N88-23009# Naval Air Development Center, Warminster, Pa. Air Vehicle and Crew Systems Technology Directorate.

DEVELOPMENT OF A HIGH-TEMPERATURE RESISTANT (700 F), CORROSION-PREVENTIVE ORGANIC COATING Final

Report, Oct. 1984 - Sep. 1986 STEPHEN J. SPADAFORA

11 Jul. 1987 41 p Original

contains color illustrations

(AD-A191407; NADC-87171-60) Avail: NTIS HC A03/MF A01 CSCL 11C

Current materials used in this temperature range (700 F) have significant deficiencies. Ceramic coatings provide good protection, but are difficult to apply and require a high-temperature cure.

Standard paints can be easily applied and air dry, but they provide poor protection against corrosion. While materials requiring high-temperature cure and special application equipment can be used in manufacturing processes, they are not practical for most aircraft repair and touchup applications. Therefore, for these applications, the air-dry systems are primarily used. These systems provide barrier protection against the environment.

N88-23011# Sun Refining and Marketing Co., Marcus Hooks, Pa. Applied Research and Development Dept.

TURBINE FUELS FROM TAR SANDS BITUMEN AND HEAVY
OU VOI LIME 2 PHASE 3: PROCESS DESIGN

OIL. VOLUME 2, PHASE 3: PROCESS DESIGN SPECIFICATIONS FOR A TURBINE FUEL REFINERY CHARGING SAN ARDO HEAVY CRUDE OIL Final Report, 1 Jun. 1985 - 31 Mar. 1987

A. F. TALBOT, J. R. SWESEY, and L. G. MAGILL Sep. 1987 247 p

(Contract F33615-83-C-2352)

(AD-A190120; AFWAL-TR-87-2043-VOL-2) Avail: NTIS HC A11/MF A01 CSCL 21D

An engineering design was developed for a 50,000 BPSD grass-roots refinery to produce aviation turbine fuel grades JP-4 and JP-8 from San Ardo heavy crude oil. The design was based on the pilot plant studies described in Phase 3 - Volume 1 of this report. The detailed plant design described in this report was used to determine estimated production costs.

#### 12

#### **ENGINEERING**

Includes engineering (general); communications; electronics and electrical engineering; fluid mechanics and heat transfer; instrumentation and photography; lasers and masers; mechanical engineering; quality assurance and reliability; and structural mechanics.

# A88-37108\* California Inst. of Tech., Pasadena. ROTORDYNAMIC FORCES ON CENTRIFUGAL PUMP IMPELLERS

R. FRANZ, N. ARNDT, T. K. CAUGHEY, C. E. BRENNEN, and A. J. ACOSTA (California Institute of Technology, Pasadena) IN: Conference on Fluid Machinery, 8th, Budapest, Hungary, Sept. 1987, Proceedings. Volume 1. Budapest, Akademiai Kiado, 1987, p. 252-258. refs

(Contract NAS8-33108)

The asymmetric flow around an impeller in a volute exerts a force upon the impeller. To study the rotordynamic force on an impeller which is vibrating around its machine axis of rotation, the impeller, mounted on a dynamometer, is made to whirl in a circular orbit within the volute. The measured force is expressed as the sum of a steady radial force and an unsteady force due to the eccentric motion of the impeller. These forces were measured in separate tests on a centrifugal pump with radically increased shroud clearance, a two-dimensional impeller, and an impeller with an inducer, the impeller of the HPOTP (High Pressure Oxygen Turbopump) of the SSME (Space Shuttle Main Engine). In each case, a destabilizing force was observed over a region of positive whirl.

## A88-37110 CASCADE LIFT RATIOS FOR RADIAL AND SEMIAXIAL ROTATING CASCADES

P. HERGT (Klein, Schanzlin, und Becker AG, Frankenthal, Federal Republic of Germany) IN: Conference on Fluid Machinery, 8th, Budapest, Hungary, Sept. 1987, Proceedings. Volume 1. Budapest, Akademiai Kiado, 1987, p. 324-331. refs

Hergt's (1983) method for the calculation of the lift and drag coefficients of rotating radial and semiaxial cascades is presently used to deduce the lift coefficient for a single vane in flows that

are inclined to the axis of rotation. It is shown that the cascade lifting ratios of rotating radial cascades are similar to the Weinig (1925) curves. Deductive results are obtained which support the possibility of judging a wide variety of turbomachines from a single, general viewpoint.

A88-37351

### WORLD CONGRESS ON COMPUTATIONAL MECHANICS, 1ST,

AUSTIN, TX, SEPT. 22-26, 1986, PROCEEDINGS
J. TINSLEY ODEN, ED. (Texas, University, Austin) sponsored by the University of Texas, NSF, U.S. Navy, et al. Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 64, Oct. 1987, 585 p. For individual items see A88-37352 to A88-37368.

Recent advances in computational mechanics are examined in reviews and reports. Topics addressed include CFM, mesh generation and rezoning, solid mechanics, and numerical methods and supercomputing. Particular attention is given to a deterministic view of shear turbulence; a numerical model for supersonic reacting mixing layers; simulation of transonic flow in radial compressors; engineering applications of the vortex cloud method; composite grid schemes for computational aerodynamics; nonlinear analysis of isotropic, orthotropic, and laminated plates and shells; and mixed and penalty formulations for FEM analysis of an eigenvalue probem in electromagnetism.

A88-37549

#### LIFE OF GAS TURBINE ENGINE DISKS WITH CRACKS [ZHIVUCHEST' DISKOV GTD S TRESHCHINAMI]

N. V. STEPANOV, V. N. SHLIANNIKOV, V. V. OMEL'CHENKO, and I. N. SHKANOV Problemy Prochnosti (ISSN 0556-171X), April 1988, p. 108-111. In Russian. refs

Results of a study of the deceleration of critical cracks in gas turbine disks of VT3-1 titanium alloy under conditions of low-cycle fatigue are reported. In the experiments, cracks were arrested by holes located in areas that were less stressed than the areas where the initial cracks grew from the disk grooves. It is shown that the method of crack arrest described here makes it possible to extend the life of disks by 36-60 percent.

A88-37661

### COMPUTER SIMULATION OF TURBULENT JETS AND WAKES [MODELIROVANIE NA EVM TURBULENTNYKH STRUI I

S. M. BELOTSERKOVSKII, A. V. DVORAK, A. I. ZHELANNIKOV, and V. N. KOTOVSKII IN: Problems of turbulent flows. Moscow, Izdatel'stvo Nauka, 1987, p. 129-134. In Russian. refs

The large-scale turbulence of plane jets and wakes is investigated using an ideal medium scheme. A class of problems is considered without any additional hypotheses being used. The present study is a further development of the general concept of modeling the principal features and microeffects of flow past bodies at high Reynolds numbers on the basis of nonstationary equations of an ideal medium. For smooth bodies, where separation sites are not fixed, the ideal medium model has to be supplemented by a boundary layer scheme.

National Aeronautics and Space Administration. A88-37929\*# Langley Research Center, Hampton, Va.

#### MEASUREMENT OF LEADING EDGE VORTICES FROM A DELTA WING USING A THREE COMPONENT LASER VELOCIMETER

JAMES F. MEYERS (NASA, Langley Research Center, Hampton, VA) and TIMOTHY E. HEPNER (U.S. Army, Aviation Research and Development Command, Hampton, VA) IN: Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 223-233. refs (AIAA PAPER 88-2024)

A demonstration of the capabilities of a three-component laser velocimeter to provide a detailed experimental database of a complex flow field is presented. The orthogonal three-component laser velocimeter was used to measure the leading edge vortex flow field above a 75 deg delta wing at angles-of-attack of 20.5 deg and 40.0 deg. The resulting mean velocity and turbulence intensity measurements are presented. The laser velocimeter is described in detail including a description of the data processing algorithm. A full-error analysis was conducted and the results presented.

A88-37930\*# Notre Dame Univ., Ind. VISUALIZATION TECHNIQUES FOR STUDYING HIGH ANGLE OF ATTACK SEPARATED VORTICAL FLOWS

ROBERT C. NELSON (Notre Dame, University, IN) Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 234-241. Research sponsored by the University of Notre Dame and NASA. refs (AIAA PAPER 88-2025)

Flow visualization techniques can provide information on high angle of attack separated flows around slender aircraft configurations that may be unobtainable otherwise. At large angles of attack the flow field is dominated by vortical structures originating on the forebody wing extension, wing and forward control surfaces. Several techniques that are suitable for tracking vortices in subsonic wind tunnels are introduced. A discussion of visualization photographs and quantitative data obtained from visualization studies on vortex trajectory and breakdown position on both static and dynamic wind tunnel models is presented.

#### A ROLE FOR FIBRE OPTICS IN ANTENNA MEASUREMENTS

W. M. KEMP and A. T. TICKNER (Department of Defence, Electronics Research Laboratory, Adelaide, Australia) Journal of Electrical and Electronics Engineering, Australia (ISSN 0725-2986), vol. 7, Dec. 1987, p. 278-281.

This paper describes two instrumentation systems which utilize fiber optics to improve the quality of antenna measurements. Firstly, the problems encountered in determining the free space patterns of antennas fitted to aircraft are discussed and a solution using fiber optics is given. Secondly, the problems associated with the measurement of capacitance of electrically short antennas (or open-bodied structures) is discussed and an instrument is described which can make these measurements with greatly improved accuracy.

A88-38181#

#### SOME ASPECTS OF THE RELIABILITY ANALYSIS OF AIRCRAFT STRUCTURES

DEPEI ZHU and FUJIA LIN (Northwestern Polytechnical University, Xian, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Jan. 1988, p. A41-A49. In Chinese, with abstract in English. refs

This paper briefly introduces some research concerning the reliability analysis of aircraft structures. A set of fundamental equations with some numerical examples for computing the failure rate of aircraft structures in service is presented. The numerical results are used to estimate the influence of various factors on the reliability of aircraft structures and to evaluate the current criteria of aircraft fatigue probability. Some new methods are presented and some new results are obtained with regard to the probability of detection, the distribution of initial flaw length, and the distribution of k1c.

A88-38187#

#### BEHAVIOUR OF DAMAGE TOLERANCE OF COMPOSITE AIRCRAFT STRUCTURES

ZHEN SHEN (Aircraft Structural Strength Research Institute, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Feb. 1988, p. B1-B10. In Chinese, with abstract in English. refs

An account is given of the features and performance of a manual landing flare and touchdown system capable of great precision, as demonstrated by its installation in the NASA Quiet Short-haul Research Aircraft (QSRA). The integrated cockpit display and closed-loop control employed constitutes a trajectory-augmentation system that extends QSRA flight control from augmentation of altitude, flight path angle, and airspeed, to the augmentation of the trajectory itself. The + or - 18 ft touchdown dispersion achieved is approximately equal to that obtained during aircraft carrier trials of the same aircraft.

#### A88-38448

#### INFORMATION PROPERTIES OF COMPLEX RADAR ANGULAR-COORDINATE ESTIMATES [INFORMATIVNYE SVOISTVA KOMPLEKSNYKH RADIOLOKATSIONNYKH OTSENOK UGLOVOI KOORDINATY]

G. G. DZHAVADOV Radioelektronika (ISSN 0021-3470), vol. 31. April 1988, p. 95, 96. In Russian.

An approach to evaluating the information properties of complex radar angular-coordinate estimates is developed. The results are pertinent to the meteorological-radar observation of thunderstorm activity in connection with the assurance of flight safety.

#### A88-39012#

### THE TURBULENCE CHARACTERISTICS OF A SINGLE

IMPINGING JET THROUGH A CROSSFLOW
J. M. M. BARATA, D. F. G. DURAO, M. V. HEITOR (Instituto Superior Tecnico, Lisbon, Portugal), and J. J. MCGURIK (Imperial College of Science and Technology, London, England) Symposium on Turbulent Shear Flows, 6th, Toulouse, France, Sept. 7-9, 1987, Proceedings. University Park, PA, Pennsylvania State University, 1987, p. 13-5-1 to 13-5-11. Research supported by the Royal Aircraft Establishment. refs
The mean and turbulent velocity characteristics of a single

round jet impinging on a ground plate after penetrating a confined cross-flowing stream were measured using laser Doppler anemometry. Special attention was given to the effect of the velocity ratio between the jet and the cross flow for a single impingement height, examining the jet-to-cross flow velocity ratios in the range 30-73. The experimental results (relevant to the problem of estimating the flow field beneath a STOVL aircraft close to the ground) were compared with predictions of the flow field with the k-epsilon model of turbulence.

#### National Aeronautics and Space Administration. Hugh L. Dryden Flight Research Facility, Edwards, Calif. DEVELOPMENT OF A BLOCK LANCZOS ALGORITHM FOR FREE VIBRATION ANALYSIS OF SPINNING STRUCTURES

K. K. GUPTA (NASA, Flight Research Center, Edwards, CA) and C. L. LAWSON (Harvey Mudd College, Claremont, CA) International Journal for Numerical Methods in Engineering (ISSN 0029-5981), vol. 26, May 1988, p. 1029-1037. refs

This paper is concerned with the development of an efficient eigenproblem solution algorithm and an associated computer program for the economical solution of the free vibration problem of complex practical spinning structural systems. Thus, a detailed description of a newly developed block Lanczos procedure is presented in this paper that employs only real numbers in all relevant computations and also fully exploits sparsity of associated matrices. The procedure is capable of computing multiple roots and proves to be most efficient compared to other existing similar techniques.

#### A88-40175

#### THE ROLE OF NON-DESTRUCTIVE TESTING IN THE AIRWORTHINESS CERTIFICATION OF CIVIL AIRCRAFT **COMPOSITE STRUCTURES**

A. MAHOON (British Aerospace, PLC, Kingston-upon-Thames, England) Composites (ISSN 0010-4361), vol. 19, May 1988, p.

Airworthiness requirements for civil aircraft structures, particularly those fabricated from carbon fiber-reinforced resins. are discussed and the use of non-destructive testing to monitor the quality of these structures at each stage of development is reviewed. Non-destructive testing techniques for series-production items are described with information on the type of defects detected by the various techniques. Non-destructive testing techniques under development and future trends in the use of the proposed testing techniques are also included.

#### A88-40280

#### ADDENDUM-DEDENDUM TYPE CIRCULAR-ARC GEARS FOR AERO-ENGINE ACCESSORY DRIVE GEARBOX - A CRITICAL **ANALYSIS OF STRENGTH-TO-WEIGHT RATIO**

K. LINGAIAN (Bangalore, University, India) and K. RAMACHANDRA (Gas Turbine Research Establishment, Bangalore, India) IN: 1987 SEM Spring Conference on Experimental Mechanics, Houston, TX, June 14-19, 1987, Proceedings. Bethel, CT, Society for Experimental Mechanics, Inc., 1987, p. 424-428.

Addendum-dedendum type of Wildhaber-Novikov gears have two contact points in an axial pitch of the gear wheel. The advantage of this profile vis-a-vis all-addendum type is discussed and the bending stress induced in these profiles is studied for various profile radii by photoelastic technique. A factor of two was estimated as the bending-strength advantage for these profiles as compared to all-addendum type of gears.

#### A88-40317

#### THERMAL STATE OF A TURBOFAN ROTOR (TEPLOVOE SOSTOIANIE KOLESA TURBOVENTILIATORA

B. D. BILEKA, A. M. DIACHENKO, and I. S. ORINICHEV (AN USSR, Institut Tekhnicheskoi Teplofiziki, Kiev, Ukrainian SSR) Promyshlennaia Teplotekhnika (ISSN 0204-3602), vol. 10, no. 2, 1988, p. 49-55. In Russian.

Results of an experimental study of the thermal state of a combined turbofan rotor consisting of a peripheral turbine stage and a central fan stage are reported. In particular, attention is given to the effect of gas temperature, air flow rate, and rotation speed on temperature distributions at characteristic points of the rotor. The relative dimensionless temperatures of the turbofan rotor are shown to be constant under all the regimes investigated. An approximate method is proposed for calculating the temperature of the rotor elements, and the results of calculations are compared with experimental data.

#### A88-40327

#### THE ROLE OF ELECTRON MICROSCOPY IN GAS TURBINE **MATERIALS DEVELOPMENT**

R. A. SPRAGUE (GE Engineering Materials and Technology Laboratories, Lynn, MA) and R. W. SMASHEY (GE Laboratory Service Technology, Cincinnati, OH) IN: MiCon 86: Optimization of processing, properties, and service performance through microstructural control; Proceedings of the Symposium, Philadelphia, PA, May 15, 16, 1986. Philadelphia, PA, American Society for Testing and Materials, 1988, p. 165-182. refs

The application of electron microscopy techniques to gas turbine materials development and its practical benefit to aircraft engine materials and process development are addressed. Scanning electron microscopy, image analysis, electron microprobe analysis, and analytical electron microscopy are considered, giving application examples. Future analytical development needs are briefly discussed.

#### A88-40535#

#### FLAT PANEL DISPLAY TRENDS

TAKEAKI SHIGETO Japan Society for Aeronautical and Space Sciences, Journal (ISSN 0021-4663), vol. 36, no. 408, 1988, p. 35-39. In Japanese.

#### A88-40713\*# Old Dominion Univ., Norfolk, Va. AERODYNAMIC INVESTIGATION BY INFRARED IMAGING

A. SIDNEY ROBERTS, JR., GRIFFITH J. MCREE (Old Dominion University, Norfolk, VA), and EHUD GARTENBERG IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 121-128. (Contract NAG1-735)

(AIAA PAPER 88-2523)

Infrared imaging systems can be used to measure temperatures of actively heated bodies immersed in an airstream. This monitoring of the convective heat transfer process, provides also information about the interaction between the body and the flow. The concept appeals to Nusselt/Reynolds numbers relations in order to produce data of interest from surface temperatures. Two test cases are presented and reference is made to analytical results: the mapping of a laminar jet and the temperature distribution along a constant power heated flat plate in laminar boundary layer regime. Although this research is currently focused on low speed aerodynamics, the extension to high speed aerodynamics, where the body undergoes frictional heating is of interest in this context, too.

Author

## A88-40759# MODELLING THE INFLUENCE OF SMALL SURFACE DISCONTINUITIES IN TURBULENT BOUNDARY LAYERS

H. H. NIGIM (Birzeit University, Jordan) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 561-567. refs (AIAA PAPER 88-2594)

The paper is concerned with flow modeling in the presence of small isolated surface discontinuities, such as those formed on aircraft wings around auxiliary lifting and control surfaces. Methods of determining step changes in the boundary layer integral parameters are developed and techniques for modeling the consequent reattaching sub-boundary layer are discussed. Examples of flow prediction results are given which compare favorably with experimental data. This modeling could easily be adapted to become an adjunct to any integral boundary layer prediction technique.

#### A88-40871#

## ASSESSMENT OF TRANSIENT TESTING TECHNIQUES FOR ROTOR STABILITY TESTING

FREDERICK A. TASKER and INDERJIT CHOPRA (Maryland, University, College Park) AIAA, ASME, ASCE, and AHS, Structures, Structural Dynamics and Materials Conference, 29th, Williamsburg, VA, Apr. 18-20, 1988. 13 p. refs (Contract DAAG29-83-K-0002) (AIAA PAPER 88-2401)

The task of estimating the damping of any mode for a helicopter rotor becomes complicated by the presence of undamped responses at the rotor harmonics, high measurement noise, the presence of close modes and the difficulty of exciting modes in the rotating environment. A systematic assessment of two transient data analysis techniques, the Moving-Block analysis method and the Sparse Time Domain technique for online estimation of damping is performed using a numerical simulation. Two refinements in Moving-Block analysis are introduced; recursive spectral analysis with improved frequency resolution, and a simple frequency domain interpretation for the Hanning window to reduce leakage from close modes. The recently developed Spare Time Domain technique is also applied to damping estimation from the numerically simulated transient response data. This technique reduces the time response into an eigenvalue problem of a sparse upper Hessenberg matrix. The effect of the Singular Value Decompositon solution technique on this method, is studied. The performance evaluation of both analysis techniques is made for noisy data, close damped and undamped modes, and for low and high damping levels. Moving-Block analysis is a simple technique and is quite effective in estimating the damping of a mode from noisy data, whereas the Sparse Time Domain is very effective in estimating the damping Author of close modes.

## A88-41219 ANALYSIS OF LIMIT CYCLE FLUTTER OF AN AIRFOIL IN INCOMPRESSIBLE FLOW

Z. C. YANG and L. C. ZHAO (Northwestern Polytechnical University, Xian, People's Republic of China) Journal of Sound and Vibration (ISSN 0022-460X), vol. 123, May 22, 1988, p. 1-13. refs

Experimental and theoretical results are presented on several types of self-excited oscillations of a two-dimensional wing model with nonlinear pitching stiffness. A double limit cycle flutter is noted

in low speed wind tunnel testing of a wing model with free play in pitch. Harmonic balance analyses confirm these sustained oscillations and reveal two other unstable limit cycles. Flutter analysis is performed using a digital simulation method. Good agreement is obtained between theoretical and experimental results.

N88-22276# Hughes Aircraft Co., El Segundo, Calif.
ADVANCED CAPACITOR DEVELOPMENT Interim Report, Oct.
1984 - Apr. 1986

ROBERT S. BURITZ 1987 158 p (Contract F33615-84-C-2424)

(AD-A189985; AFWAL-TR-86-2073) Avail: NTIS HC A08/MF A01 CSCL 09A

This document describes the technical approach taken by Hughes Aircraft Company for the development and testing of ac filter capacitors for airborne applications which will have a higher operating temperature than presently available. This program will result in improved lightweight, highly reliable filter capacitors operating at ambient temperatures exceeding 200 C, which will significantly advance the state of the art in capacitor technology. Two problems faced in achieving higher operating temperatures are the temperature limitation of the dielectric materials and thermal management of the heat generated. Failures are usually caused by the dissipation of relatively large amounts of power in a poorly cooled volume. These failures can take the form of thermal runaway, insulation failure because of very great local hot-spot temperatures, and excessive thermal expansion. Because the thermal properties of films available for capacitor use range from about 115 to more than 450 C, operating temperatures up to 300 to 400 C appear to be feasible. Since these numbers far exceed operating temperatures reported in the literature, the question arises as to the reason for the large difference. than 450 C, operating temperatures up to 300 to 400 C appear to be feasible. Since these numbers far exceed operating temperatures reported in the literature, the question arises as to the reason for the large difference.

N88-22290# Instituto Nacional de Tecnica Aeroespacial, Esteban Terradas, Torrejon de Ardoz (Spain). Dept. de Aerodinamica y Navegabilidad.

A PANEL METHOD BASED ON VELOCITY POTENTIAL TO COMPUTE HARMONICALLY OSCILLATING LIFT SURFACE SYSTEMS [METODO DE PANELES BASADO EN EL POTENCIAL DE VELOCIDADES PARA EL CALCULO DE SISTEMAS DE SUPERFICIES SUSTENTADORAS OSCILANTES ARMONICAMENTE]

LUIS P. RUIZCALAVERA 1987 13 p In SPANISH; ENGLISH summary Presented at the 5th International Congress on Numerical Methods in Laminar and Turbulent Flow, Montreal, Quebec, 6-10 Jul. 1987

(ETN-88-91886) Avail: NTIS HC A03/MF A01

A numerical method to calculate unsteady pressure distributions on systems of interferring lifting surfaces harmonically oscillating in incompressible flow was developed. Unlike the conventional approach to this kind of problem which use Prandtl's acceleration potential, this method is based on the velocity potential, whose simplicity allows to take into account thickness effects. Special attention is paid to the treatment of the wake influence, by far the most difficult problem in this type of method. The linearized version shows excellent agreement with techniques based on acceleration potential.

N88-22300# Technion - Israel Inst. of Tech., Haifa.
VISUALISATION OF THE FLOW AT THE TIP OF A HIGH
SPEED AXIAL FLOW TURBINE ROTOR Final Report
J. BINDON, D. ALDER, and I. IANOVICI Nov. 1987 60 p

(Contract AF-AFOSR-0308-85) (AD-A189928) Avail: NTIS HC A04/MF A01 CSCL 20D

The previous work having relevance to the flow in the region of an unshrouded turbine rotor blade tip was examined. It was found that, although extensive information is available on the effect of leakage flow on the loss mechanisms on the suction side of

the blade, an almost complete dearth of detailed information exists on the flow structure and mechanisms in the pressure side corner and tip gap regions which are considered important with respect to blade cooling. It would thus seem essential to lay a foundation of understanding from simple models and ending with the complex full speed situation. A logical qualitative prediction of the expected flows is presented. Apart from being complex with various zones of flow behaving almost independently from each other, the effect of upstream tangential unsymmetry (nozzle wakes) was shown to complicate the flow visualization technique and render the normal type of continuous tracer injection of no use. Thus either an experimental rig is required which has tangentially uniform flow upstream of the rotor or a new type of pulse trace technique is needed. It is suggested that both of these requirements be adopted.

N88-22305# Grumman Aerospace Corp., Bethpage, N.Y. Corporate Research Center.

ON THE PREDICTION OF HIGHLY VORTICAL FLOWS USING AN EULER EQUATION MODEL, PART 2 Final Report, 31 Jul. 1985 - 31 Jul. 1987

FRANK MARCONI 30 Oct. 1987 137 p (Contract F49620-85-C-0115)

(AD-A190245; AFOSR-87-1910TR-PT-2) Avail: NTIS HC

A07/MF A01 CSCL 20D

An investigation of the power of the Euler equations in the prediction of conical separated flows is presented. These equations are solved numerically for the highly vortical supersonic flow about simple bodies. Two sources of vorticity are studied: the first is the flow field shock system and the second is the vorticity shed into the flow field from a separating boundary layer. Both sources of vorticity are found to produce separation and vortices. In the case of shed vorticity, the surface point from which the vorticity is separation point) is determined empirically. At very high angles of attack the only stable separated solution is found to be asymmetric. Solutions obtained with both sources of vorticity are studied in detail, compared with each other and with potential calculations and experimental data.

N88-22320# Illinois Univ., Urbana. Dept. of Mechanical and Industrial Engineering.

NUMERICAL AND EXPERIMENTAL INVESTIGATION OF MULTIPLE SHOCK WAVE/TURBULENT BOUNDARY LAYER INTERACTIONS IN A RECTANGULAR DUCT Final Technical Report, 1 Jul. 1985 - 31 Dec. 1987

J. C. DUTTON and B. F. CARROLL 6 Jan. 1988 115 p (Contract N00014-85-K-0665)

(AD-A190772; UILU-ENG-88-4001) Avail: NTIS HC A06/MF A01 CSCL 20D

Multiple shock wave/turbulent boundary layer interactions in constant or nearly constant area supersonic duct flows occur in a variety of devices including scramjet inlets, gas ejectors, and supersonic wind tunnels. For sufficiently high duct exit pressures, a multiple shock wave/turbulent boundary layer interaction or shock train may form in the duct and cause a highly nonuniform, and possibly unsteady, flow at the duct exit. In this report, the mean flow characteristics of two shock train interactions, one with an initial Mach number of 2.5 the other at Mach 1.6, are investigated using spark Schlieren photography, surface oil flow visualization, and mean wall pressure measurements. The Mach 2.5 interaction was oblique and asymmetric in nature. A large separation occurs after the first oblique shock. The top and bottom wall boundary layer separation has been investigated, revealing that the shape of the reattachment lines and surface flow patterns for the two separation regions are quite different. This oblique shock flow pattern occurs in a neurally stable fashion with each type of opposing separation region alternately existing on either the top or bottom wall during the course of a run. A small scale unsteadiness in the shock train location, with movement on the order of a boundary layer thickness, is also observed.

N88-22325\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

AEROTHERMAL TESTS OF QUILTED DOME MODELS ON A FLAT PLATE AT A MACH NUMBER OF 6.5

CHRISTOPHER E. GLASS and L. ROANE HUNT May 1988 72 p

(NASA-TP-2804; L-16346; NAS 1.60:2804) Avail: NTIS HC A04/MF A01 CSCL 20D

Aerothermal tests were conducted in the NASA Langley 8 Foot High Temperature Tunnel (8'HTT) at a Mach number of 6.5 on simulated arrays of thermally bowed metallic thermal protection system (TPS) tiles at an angle of attack of 5 deg. Detailed surface pressures and heating rates were obtained for arrays aligned with the flow and skewed 45 deg diagonally to the flow with nominal bowed heights of 0.1, 0.2, and 0.4 inch submerged in both laminar and turbulent boundary layers. Aerothermal tests were made at a nominal total temperature of 3300 R, a total pressure of 400 psia, a total enthalpy of 950 Btu/lbm, a dynamic pressure of 2.7 psi, and a unit Reynolds number of 400,000 per foot. The experimental results form a data base that can be used to help protect aerothermal load increases from bowed arrays of TPS tiles.

Author

N88-22326°# National Aeronautics and Space Administration, Washington, D.C.

**DESIGNS OF PROFILES FOR CASCADES** 

L. GOETTSCHING Apr. 1988 30 p Transl. into ENGLISH from Thermodynamic and Flow Mechanical Problems in Aircraft and Spacecraft Drives (Fed. Republic of Germany, Stuttgart Univ.), Apr. 1986 p 243-267 Transl. by Scientific Translation Service, Santa Barbara, Calif. Original language document was announced as N87-14340

(Contract NASW-4307)

(NASA-TT-20161; NAS 1.77:20161; ETN-87-98751) Avail: NTIS HC A03/MF A01 CSCL 20D

Optimized cascade profiles for arbitrary applications were designed. The influence of Mach number, Reynolds number, and degree of turbulence were taken into account. The optimization aimed at maximum pressure increase, minimum pressure loss, low Reynolds number dependence, or large angle-of-attack range. Starting from the boundary layer form parameter distribution (by which transition point and separation point can be controlled) the velocity distribition and the contour were calculated. The profile characteristics were tested off-design and were improved. Interferometric measurements were performed in the transonic cascade channel.

N88-22330# Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Goettingen (West Germany). Inst. fuer Theoretische Stroemungsmechanik.

THEORETICAL INVESTIGATION OF SECONDARY INSTABILITY OF THREE-DIMENSIONAL BOUNDARY-LAYER FLOWS WITH APPLICATION TO THE DFVLR-F5 MODEL WING

THOMAS M. FISCHER and UWE DALLMANN Sep. 1987 64 p (DFVLR-FB-87-44; ISSN-0171-1342; ETN-88-92113) Avail: NTIS HC A04/MF A01; DFVLR, VB-PL-DO, 90 60 58, 5000 Cologne, Federal Republic of Germany, 20.50 deutsche marks

The transition of a laminar three-dimensional boundary-layer flow to a turbulent flow was studied. The transition is governed by nonlinear interactions between stationary vortex structures and instationary disturbances. In order to incorporate such interactions into a transition model, the boundary layer flow being primarily disturbed by the stationary so-called crossflow vortices was investigated locally for secondary instability. Results for the boundary layer of a swept model wing show the importance of waves traveling preferably oblique to the direction of the external inviscid flow.

N88-22369# National Aerospace Lab., Amsterdam (Netherlands). Informatics Div.

RELIABILITY ANALYSIS WITHIN A COMPUTER AIDED ENGINEERING (CAE) INFRASTRUCTURE

P. J. H. M. MANDERS and D. W. V.D.KWAAK 30 Sep. 1986 11 p Presented at the Reliability and Maintainability Symposium, Philadelphia, Penn., Jan. 1987

(NLR-MP-86059-U; B8733100; ETN-88-92223) Avail: NTIS HC A03/MF A01

A computer aided engineering (CAE) infrastructure for supporting the development of electronic systems, and the evaluation, and introduction, of software packages for reliability analysis of electronic systems under development is described. Prior conditions, functional requirements, performance characteristics, and implementation aspects of the CAE infrastructure as well as the reliability analysis software package are presented. The importance of a standard for common design information in the CAE infrastructure through all projects stages is discussed, and the influence of the CAE infrastructure on the requirement for reliability analysis is assessed.

N88-22382\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

### LEWIS STRUCTURES TECHNOLOGY, 1988. VOLUME 2: STRUCTURAL MECHANICS

May 1988 307 p Symposium held in Cleveland, Ohio, 24-25 May 1988

Lewis Structures Div. performs and disseminates results of research conducted in support of aerospace engine structures. These results have a wide range of applicability to practitioners of structural engineering mechanics beyond the aerospace arena. The engineering community was familiarized with the depth arange of research performed by the division and its academic and industrial partners. Sessions covered vibration control, fracture mechanics, ceramic component reliability, parallel computing, nondestructive evaluation, constitutive models and experimental capabilities, dynamic systems, fatigue and damage, wind turbines, hot section technology (HOST), aeroelasticity, structural mechanics codes, computational methods for dynamics, structural optimization, and applications of structural dynamics, and structural mechanics computer codes.

## N88-22393\*# Sverdrup Technology, Inc., Cleveland, Ohio. SPECIALTY THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS CODES

JOSEPH J. LACKNEY In NASA. Lewis Research Center, Lewis Structures Technology, 1988. Volume 2: Structural Mechanics p 123-129 May 1988

Avail: NTIS HC A14/MF A01 CSCL 20K

General purpose finite element computer codes that can model inelastic material behavior have been available for more than a decade. However, these codes have not been accurate enough for use in analyzing hot section engine components. To correct this problem, General Electric developed a series of nine new stand-alone computer codes for NASA. Because of the large temperature excursions associated with hot section engine components, these codes have been designed to accommodate broad variations in material behavior, including plasticity and creep. The capabilities of these computer codes are summarized.

Author

N88-22418\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

#### **MODE 2 FRACTURE MECHANICS**

ROBERT J. BUZZARD and LOUIS GHOSN (Cleveland State Univ., Ohio.) In its Lewis Structures Technology, 1988. Volume 3: Structural Integrity Fatigue and Fracture Wind Turbines HOST p 149-159 May 1988 (Contract NCC3-46)

Avail: NTIS HC A16/MF A01 CSCL 20K

Current development of high-performance rolling element bearings for aircraft engines (up to 3 million DN, where DN is the product of shaft diameter in millimeters and speed in revolutions per minute) has aroused concern about fatigue crack growth in the inner bearing race that leads to catastrophic failure of the

bearing and the engine. A failure sequence was postulated by Srawley, and an analytical program was undertaken to simulate fatigue crack propagation in the inner raceway of such a bearing. A fatigue specimen was developed at NASA by which fatigue data may be obtained relative to the cracking problems. The specimen may be used to obtain either mode 2 data alone or a combination of mixed-mode (1 and 2) data as well and was calibrated in this regard. Mixed-mode fracture data for M-50 bearing steel are presented, and a method for performing reversed-loading tests is described.

## N88-22426\*# Pratt and Whitney Aircraft, East Hartford, Conn. LIFE PREDICTION MODELING BASED ON CYCLIC DAMAGE ACCUMULATION

RICHARD S. NELSON In NASA. Lewis Research Center, Lewis Structures Technology, 1988. Volume 3: Structural Integrity Fatigue and Fracture Wind Turbines HOST p 245-257 May 1988 (Contract NAS3-23288)

Avail: NTIS HC A16/MF A01 CSCL 14D

A high temperature, low cycle fatigue life prediction method was developed. This method, Cyclic Damage Accumulation (CDA), was developed for use in predicting the crack initiation lifetime of gas turbine engine materials, where initiation was defined as a 0.030 inch surface length crack. A principal engineering feature of the CDA method is the minimum data base required for implementation. Model constants can be evaluated through a few simple specimen tests such as monotonic loading and rapic cycle fatigue. The method was expanded to account for the effects on creep-fatigue life of complex loadings such as thermomechanical fatigue, hold periods, waveshapes, mean stresses, multiaxiality, cumulative damage, coatings, and environmental attack. A significant data base was generated on the behavior of the cast nickel-base superalloy B1900+Hf, including hundreds of specimen tests under such loading conditions. This information is being used to refine and extend the CDA life prediction model, which is now nearing completion. The model is also being verified using additional specimen tests on wrought INCO 718, and the final version of the model is expected to be adaptable to most any high-temperature alloy. The model is currently available in the form of equations and related constants. A proposed contract addition will make the model available in the near future in the form of a computer code to potential users.

N88-22430\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

#### **RESEARCH SENSORS**

DAVID R. ENGLUND *In its* Lewis Structures Technology, 1988. Volume 3: Structural Integrity Fatigue and Fracture Wind Turbines HOST p 323-335 May 1988
Avail: NTIS HC A16/MF A01 CSCL 14B

The work described is part of a program (Englund and Seasholtz, 1988) to develop sensors and sensing techniques for research applications on aircraft turbine engines. In general, the sensors are used to measure the environment at a given location within a turbine engine or to measure the response of an engine component to the imposed environment. Locations of concern are generally in the gas path and, for the most part, are within the hot section. Specific parameters of concern are dynamic gas temperature, heat flux, airfoil surface temperature, and strain on airfoils and combustor liners. To minimize the intrusiveness of surface-mounted sensors, a considerable effort was expended to develop thin-film sensors for surface temperature, strain, and heat flux measurements. In addition, an optical system for viewing the interior of an operating combustor was developed. Most of the work described is sufficiently advanced that the sensors were used and useful data were obtained. The notable exception is the work to develop a high-temperature static strain measuring capability; the work is still in progress. Author

N88-22434\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va. IMPROVEMENTS TO TILT ROTOR PERFORMANCE THROUGH PASSIVE BLADE TWIST CONTROL

MARK W. NIXON (Army Aviation Systems Command, St. Louis, Mo.) Apr. 1988 11 p (NASA-TM-100583; NAS 1.15:100583; AVSCOM-TM-88-B-010) Avail: NTIS HC A03/MF A01 CSCL 20K

A passive blade twist control is presented in which the twist distribution of a tilt rotor blade is elastically changed as a function of rotor speed. The elastic twist deformation is used to achieve two different blade twist distributions corresponding to the two rotor speeds used on conventional tilt rotors in hover and forward flight. By changing the blade twist distribution, the aerodynamic performance can be improved in both modes of flight. The concept presented obtains a change in twist distribution with extension-twist-coupled composite blade structure. This investigation first determines the linear twists which are optimum for each flight mode. Based on the optimum linear twist distributions, three extension-twist-coupled blade designs are developed using coupled-beam and laminate analyses integrated with an optimization analysis. The designs are optimized for maximum twist deformation subject to material strength limitations. The aerodynamic performances of the final designs are determined which show that the passive blade twist control concept is viable, and can enhance conventional tilt rotor performance.

N88-22446\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

#### STRUCTURAL DYNAMICS BRANCH RESEARCH AND **ACCOMPLISHMENTS FOR FISCAL YEAR 1987** May 1988 34 p

(NASA-TM-100279; E-3920; NAS 1.15:100279) Avail: NTIS HC A03/MF A01 CSCL 20K

This publication contains a collection of fiscal year 1987 research highlights from the Structural Dynamics Branch at NASA Lewis Research Center. Highlights from the branch's four major work areas, Aeroelasticity, Vibration Control, Dynamic Systems, and Computational Structural Methods, are included in the report as well as a complete listing of the FY87 branch publications.

National Aeronautics and Space Administration. N88-23127\*# Ames Research Center, Moffett Field, Calif.

#### **VORTEX BREAKDOWN AND CONTROL EXPERIMENTS IN** THE AMES-DRYDEN WATER TUNNEL

F. K. OWEN (Complere, Inc., Palo Alto, Calif.) and D. J. PEAKE In AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 10 p Jun. 1987 Previously announced as N87-13409

Avail: NTIS HC A20/MF A01 CSCL 20D

Flow-field measurements have been made to determine the effects of core blowing on vortex breakdown and control. The results of these proof-of-concept experiments clearly demonstrate the usefulness of water tunnels as test platforms for advanced flow-field simulation and measurement. Author

### N88-23130# Eidetics International, Inc., Torrance, Calif. FLOW VISUALIZATION STUDY OF VORTEX MANIPULATION ON FIGHTER CONFIGURATIONS AT HIGH ANGLES OF

GERALD N. MALCOLM and ANDREW M. SKOW In AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 19 p Jun. 1987 (Contract F33615-85-C-3619)

Avail: NTIS HC A20/MF A01

Experiments were performed in a flow visualization water tunnel on a generic fighter model to explore vortex manipulation as an effective means of aircraft control by altering the natural state of the forebody and LEX vortices in the medium-to-high-angle of attack range with either small surface modifiers or blowing jets. Specifically, the forebody vortex system was examined with the clean forebody, with forebody strakes, and with forebody surface blowing. LEX vortices were examined with a clean LEX, with small geometric modifications near the apex, and with surface blowing,

both in upstream and downstream directions at various locations

on the LEX surface. The interactive effects of forebody and

LEX/wing vortices and their response to the various methods of control were also examined. It was concluded that the forebody vortices can be effectively controlled by either blowing or using strakes, but the effectiveness is very dependent on proper radial placement of the blowing port or strake.

#### N88-23134# Technische Hochschule, Aachen (West Germany). SHORT DURATION FLOW ESTABLISHMENT ON A PROFILE IN A WATER-LUDWIEG-TUNNEL

W. KERRES and H. GROENIG In AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 12 p Jun.

Avail: NTIS HC A20/MF A01

This paper deals with the time-dependent establishment of the flow field on an airfoil in unsteady flow. The impulsive part of the flow is achieved in a Water-Ludwieg-Tunnel. By using a coded particle tracing method for flow visualization, the detailed flow establishment on a NACA 0012 airfoil at 30-deg angle of attack is shown from the beginning where potential flow exists with zero circulation to a quasi-steady formation of the vortex street.

#### N88-23135# McDonnell-Douglas Research Labs., St. Louis, Mo. EXPERIMENTAL INVESTIGATION OF HOVER FLOWFIELDS IN WATER AT THE MCDONNELL DOUGLAS RESEARCH **LABORATORIES**

K. R. SARIPALLI, J. C. KROUTIL, and J. R. VANHORN AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 10 p Jun. 1987 Avail: NTIS HC A20/MF A01

A new experimental facility, the Hover Research Facility (HRF), is designed to study the flowfields generated by hovering vertical takeoff and landing (VTOL) aircraft and helicopters. Water is used as the working medium because of its inherent advantages in flow visualization and laser Doppler velocimeter (LDV) measurements. The applications of the Hover Research Facility include: (1) experimental investigation of twin-jet impingement flow with application to VTOL aircraft; (2) visualization of the flowfield around a fully contoured, model supersonic fighter/attack short takeoff and vertical landing (STOVL) aircraft; and (3) performance testing of a No Tail Rotor (NOTAR) helicopter in hover mode by use of a scale model. Flow visualization and quantitative LDV data on these experiments are presented. Author

#### N88-23137# Leicester Univ. (England). Dept. of Engineering. MEASUREMENTS OF AERODYNAMIC FORCES ON UNSTEADILY MOVING BLUFF PARACHUTE CANOPIES D. J. COCKRELL, R. J. HARWOOD, and C. Q. SHEN In AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 7 p Jun. 1987

Avail: NTIS HC A20/MF A01 Equations which describe the unsteady motion of bluff bodies through fluids contain certain components, termed added mass coefficients, which can only be determined by experiment. From the solutions to such equations the ways in which the shapes of parachute canopies influence the frequency of their oscillatory motion in pitch and their corresponding damping rates are required. Although a full-scale parachute canopy descends through air. oscillating in pitch as it does, experiments necessary to determine these added mass coefficients have been performed under water, using for this purpose a large ship tank from the towing carriage of which the model parachute canopies were suspended. These experiments showed that the added mass coefficients for bluff parachute canopies differed appreciably from their corresponding potential flow values. The latter were obtained from the analysis of inviscid, fluid flow around regular shapes which were representative of those parachute canopies. The significance for the prediction of the parachute's dynamic behavior in pitch is outlined. **Author** 

N88-23138# IMI Summerfield, Kidderminster (England). WATER FLOW VISUALISATION OF A RAMROCKET **COMBUSTION CHAMBER** 

P. J. BOSZKO and G. S. OWEN In AGARD, Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 11 p Sponsored in part by Ministry of Defence

Avail: NTIS HC A20/MF A01

Flow within the combustion chamber of a ramrocket has been investigated using water flow visualization with air bubbles as tracers. Configurations with four axisymmetric intakes entering the combustion chamber at either 45 or 90 deg have been considered. A region of stable recirculatory flow has been identified at the head end of the combustion chamber and estimates have been obtained of the amount flowing through the recirculation region. Based on this information fuel jets have been designed which it is believed will aid ignition, secure flame stability, and improve combustion efficiency. The interaction between fuel jets and the recirculatory air flow has been tentatively investigated on flow visualization tests using jets of colored water.

Office National d'Etudes et de Recherches N88-23139# Aerospatiales, Paris (France).

#### THE ONERA WATER TUNNELS TEST POSSIBILITIES FOR FLOW VISUALIZATION IN AERONAUTICAL AND NAVAL **DOMAINS**

In AGARD, Aerodynamic and Related Hydrodynamic H. WERLE Jun. 1987 In FRENCH; Studies Using Water Facilities 16 p **ENGLISH summary** 

Avail: NTIS HC A20/MF A01

The ONERA water test tunnels, which for a long time were the pioneers in flow visualization, cover a broad scope of test methods and means, encompassing a wide field of applications. This paper presents an up-to-date description of the experimental techniques used for plane, axisymmetric and three-dimensional flow, and gives a survey of the most notable results achieved in domains as varied as fundamental research and aerodynamics and related hydrodynamic studies.

N88-23152# Saab-Scania, Linkoping (Sweden). INVESTIGATION ON THE MOVEMENT OF VORTEX BURST POSITION WITH DYNAMICALLY CHANGING ANGLE OF ATTACK FOR A SCHEMATIC DELTAWING IN A WATERTUNNEL WITH CORRELATION TO SIMILAR STUDIES IN WINDTUNNEL

In AGARD, Aerodynamic and Related KARL W. WOLFFELT Hydrodynamic Studies Using Water Facilities 8 p Avail: NTIS HC A20/MF A01

The requirements for modern military aircraft to maintain good handling qualities at very high angles of attack is one of many reasons why an increased knowledge is necessary regarding the aerodynamic behavior of vortex flows at nonstationary conditions. Linearized theory as it has been utilized in flight mechanics simulation using damping derivatives derived from forced oscillation technique, for example, may no longer be valid at such conditions. With this background some investigations have been made by SAAB-SCANIA with the aim to study the hysteresis effects for nonstationary vortex flows. A schematic delta-wing model which could also be equipped with a similar canard wing has been tested in a water tunnel. The model was supported in the tunnel by a simple mechanism by which it could be forced to move in one of four different modes, pitching or plunging with either ramp or harmonic motion. The flow over the model was visualized with air bubbles and sequences were recorded on videotape. The sequences were analyzed and the movements of the leading edge vortex burst have been studied with the main interest focused on Author the hysteresis effects.

#### N88-23155# Hamburg Model Basin (West Germany). MEASUREMENTS OF THE TIME DEPENDENT VELOCITY FIELD SURROUNDING A MODEL PROPELLER IN UNIFORM WATER FLOW

JOERG BLAUROCK and GERD LAMMERS In AGARD. Aerodynamic and Related Hydrodynamic Studies Using Water Facilities 13 p Jun. 1987

Avail: NTIS HC A20/MF A01

As part of a research program, the flow field around an operating

ship propeller was investigated in a water tunnel, using laser Doppler velocimetry. The 3-D velocity field was measured in three planes at the suction side and four planes on the pressure side of the propeller at the design thrust coefficient of K sub T = 0.185. In one of the planes in the propeller's slipstream, the measurements were repeated at thrust coefficients of K sub T = 0.12 and 0.25. The volocity profiles measured in the propeller's slipstream are compared with the induced velocities derived from design calculations, and occurring deviations are discussed. Furthermore, the instationary flow field permits study of the tip vortices at different distances behind the propeller. The measurements yield a quantitative description of the vortices, and the influence of propeller load at the blade tips on geometry and intensity of the tip vortices can be seen.

Old Dominion Univ., Norfolk, Va. Dept. of N88-23160\*# Mechanical Engineering and Mechanics.

NONLINEAR WAVE INTERACTIONS IN SWEPT WING FLOWS NABIL M. ELHADY May 1988 53 p (Contract NAG1-729)

(NASA-CR-4142; NAS 1.26:4142) Avail: NTIS HC A04/MF A01 CSCL 20D

An analysis is presented which examines the modulation of different instability modes satisfying the triad resonance condition in time and space in a three-dimensional boundary layer flow. Detuning parameters are used for the wave numbers and the frequencies. The nonparallelism of the mean flow is taken into account in the analysis. At the leading-edge region of an infinite swept wing, different resonant triads are investigated that are comprised of travelling crossflow, vertical vorticity and Tollmein-Schlichting modes. The spatial evolution of the resonating triad components are studied.

Office National d'Etudes et de Recherches Aerospatiales, Paris (France).

LA RECHERCHE AEROSPATIALE, BIMONTHLY BULLETIN. **NUMBER 1987-3, 238/MAY-JUNE** 

ESA Nov. 1987 72 p

(ESA-TT-1075; ETN-88-91977) Avail: NTIS HC A04/MF A01 Validation of turbulence models applied to transonic shock-wave/boundary-layer interaction; effect of computation parameters on the results of 3-D potential methods; infrared signature of flames: spectral data of carbon dioxide at high temperature: time stability of schemes using high order spatial discretization in the case of a convection equation; and flow around a symmetrical profile (hydrodynamic visualizations) are discussed.

### N88-23169# European Space Agency, Paris (France). COMPARISON OF DIFFERENT KINDS OF COMPACT **CROSSFLOW HEAT EXCHANGERS**

WERNER SIEMENS (Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Cologne, West Germany ) Mar. 1988 80 p Transl. into ENGLISH of Vergleichende Rechnungen an Kompakten Platten- und Profil-Waermetauschern (Cologne, Fed. REpublic of Germany, DFVLR), Sep. 1986 82 p Original language document was announced as N88-10305

(ESA-TT-1076; DFVLR-FB-86-63; ETN-88-92558) Avail: NTIS HC A05/MF A01; original German version available from DFVLR, VB-PL-DO, 90 60 58, 5000 Cologne, Fed. Republic of Germany 29.50 DM

A computer program for the calculation of compact heat exchangers for gas turbines was developed. The most important coefficients, pressure drops, and effectiveness of different kinds of exchangers were calculated as a function of Mach number, the dimensions of the exchanger, and the compactness. From the aerothermodynamic point of view, the plate exchanger is best, closely followed by the lancet heat exchanger. The ribs of the plate version have no significant effect on the characteristics, but are required for stiffness and uniform channel height. The tube heat exchanger can only compete as far as the transferable heat is concerned.

N88-23171\*# Stanford Univ., Calif. Dept. of Aeronautics and Astronautics.

EXPERIMENTAL STUDIES OF VORTEX FLOWS Final Report, Mar. 1984 - May 1988

L. ROBERTS and R. MEHTA Jun. 1988 8 p (Contract NCC2-294)

(NASA-CR-182874; NAS 1.26:182874) Avail: NTIS HC A02/MF A01 CSCL 20D

This final report describes research work on vortex flows done during a four-year period beginning in March 1984 and funded by NASA Grant NCC2-294 from the Fluid Dynamics Research Branch of NASA Ames Research Center. After a brief introduction of the main topics addressed by the completed research, the accomplishments are summarized in chronological order. Author

N88-23220\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

### COMPUTERIZED LIFE AND RELIABILITY MODELLING FOR TURBOPROP TRANSMISSIONS

M. SAVAGE, K. C. RADIL, D. G. LEWICKI (Army Aviation Research and Development Command, St. Louis, Mo.), and J. J. COY 1988 17 p Presented at the 24th Joint Propulsion Conference, Boston, Mass., 11-13 Jul. 1988; sponsored by AIAA, ASEE, ASME and SAE

(Contract DA PROJ. 1L1-61102-AH-45)

(NASA-TM-100918; E-4173; NAS 1.15:100918;

AVSCOM-TR-87-C-37; AIAA-88-2979) Avail: NTIS HC A03/MF A01 CSCL 13I

A generalized life and reliability model is presented for parallel shaft geared prop-fan and turboprop aircraft transmissions. The transmission life and reliability model is a combination of the individual reliability models for all the bearings and gears in the main load paths. The bearing and gear reliability models are based on classical fatigue theory and the two parameter Weibull failure distribution. A computer program was developed to calculate the transmission life and reliability. The program is modular. In its present form, the program can analyze five different transmission arrangements. However, the program can be modified easily to include additional transmission arrangements. An example is included which compares the life of a compound two-stage transmission, as calculated by the computer program.

Author

N88-23226\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

LEWIS STRUCTURES TECHNOLOGY, 1988. VOLUME 1: STRUCTURAL DYNAMICS

May 1988 463 p Symposium held in Cleveland, Ohio, 24-25 May 1988

The specific purpose of the symposium was to familiarize the engineering structures community with the depth and range of research performed by the Structures Division of the Lewis Research Center and its academic and industrial partners. Sessions covered vibration control, fracture mechanics, ceramic component reliability, parallel computing, nondestructive testing, dynamical systems, fatigue and damage, wind turbines, hot section technology, structural mechanics codes, computational methods for dynamics, structural optimization, and applications of structural dynamics.

N88-23229\*# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

### PIEZOELECTRIC PUSHERS FOR ACTIVE VIBRATION CONTROL OF ROTATING MACHINERY

ALAN B. PALAZZOLO (Texas A&M Univ., College Station.) and ALBERT F. KASCAK *In* NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 29-46 May 1988

Avail: NTIS HC A20/MF A01 CSCL 14B

The active control of rotordynamic vibrations and stability by

magnetic bearings and electromagnetic shakers have been discussed extensively in the literature. These devices, though effective, are usually large in volume and add significant weight to the stator. The use of piezoelectric pushers may provide similar degrees of effectiveness in light, compact packages. Tests are currently being conducted with piezoelectric pusher-based active vibration control. Results from tests performed on NASA test rigs as preliminary verification of the related theory are presented.

Author

N88-23230\*# Case Western Reserve Univ., Cleveland, Ohio. Dept. of Mechanical and Aerospace Engineering.

### ACTIVE CONTROL AND SYSTEM IDENTIFICATION OF ROTORDYNAMIC STRUCTURE

M. L. ADAMS In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 47-52 May 1988

Avail: NTIS HC A20/MF A01 CSCL 20K

Four current research projects are summarized: (1) active control of rotor system dynamics; (2) attenuation of rotor vibration using controlled pressure hydrostatic bearings; (3) a new seal test facility for measuring isotropic and anisotropic linear rotordynamic characteristics; and (4) the use of rotordynamic instability thresholds to accurately measure bearing rotordynamic characteristics.

Author

**N88-23244\***# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

## DEVELOPMENT OF AEROELASTIC ANALYSIS METHODS FOR TURBOROTORS AND PROPFANS, INCLUDING MISTUNING

KRISHNA RAO V. KAZA *In* NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 247-262 May 1988

Avail: NTIS HC A20/MF A01 CSCL 20K

The NASA Lewis aeroelastic research program is focused on unstalled and stalled flutter, forced response, and whirl flutter of turborotors and propfans. The objectives are to understand the physical phenomena of cascade flutter and response including blade mistuning.

Author

**N88-23253\***# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

### MODAL FORCED RESPONSE OF PROPFANS IN YAWED FLOW

G. V. NARAYANAN (Sverdrup Technology, Inc., Cleveland, Ohio.) In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 367-376 May 1988 Avail: NTIS HC A20/MF A01 CSCL 20K

A modal forced response method for propfans in yawed flow is presented. This capability exists in the Aeroelastic Stability and Response of Propfan (ASTROP3) code developed at the Lewis Research Center. The code uses three-dimensional steady and unsteady cascade aerodynamics by Williams and Hwang (1986) and a NASTRAN finite element model to represent the blade structure. In addition, many utility programs exist in ASTROP3 that help in both the preprocessing of the NASTRAN model and the postprocessing of modal response results. The postprocessing work that computes the blade vibratory displacements and stresses in yawed flow are highlighted here.

N88-23254\*# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

### VIBRATION AND FLUTTER ANALYSIS OF THE SR-7L LARGE-SCALE PROPFAN

RICHARD AUGUST (Sverdrup Technology, Inc., Cleveland, Ohio.) In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 379-392 May 1988 Avail: NTIS HC A20/MF A01 CSCL 20K

A structural and aeroelastic analysis of the SR-7L advanced turboprop is presented. Analyses were conducted for several cases at different blade pitch angles, blade support conditions, rotational speeds, free-stream Mach numbers, and number of blades. A finite element model of the final blade design was used to determine

#### 12 ENGINEERING

the blade's vibration behavior and its sensitivity to support stiffness. A computer code which was based on three-dimensional, subsonic, unsteady lifting surface aerodynamic theory, was used for the aeroelastic analysis to examine the blade's stability at a cruise condition of Mach 0.8 at 1700 rpm. The results showed that the calculated frequencies and mode shapes obtained agreed well with the published experimental data and that the blade is stable for that operating point.

N88-23255\*# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

SUPERSONIC AXIAL-FLOW FAN FLUTTER

JOHN K. RAMSEY In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 393-403 May 1988

Avail: NTIS HC A20/MF A01 CSCL 20K

Lane's (1957) analytical formulation of the unsteady pressure distribution on an oscillating two-dimensional flat plate cascade in supersonic axial flow has been developed into a computer code. This unsteady aerodynamic code has shown good agreement with other published data. This code has also been incorporated into an existing aeroelastic code to analyze the NASA Lewis supersonic through-flow fan design.

N88-23256\*# Army Aviation Systems Command, Cleveland, Ohio. Structural Dynamics Branch.

STALL FLUTTER ANALYSIS OF PROPFANS

T. S. R. REDDY (Toledo Univ., Ohio.) In NASA, Lewis Research Center, Lewis Structures Technology, 1988. Volume 1: Structural Dynamics p 405-419 May 1988 Previously announced as N87-18883

Three semi-empirical aerodynamic stall models are compared with respect to their lift and moment hysteresis loop prediction, limit cycle behavior, easy implementation, and feasibility in developing the parameters required for stall flutter prediction of advanced turbines. For the comparison of aeroelastic response prediction including stall, a typical section model and a plate structural model are considered. The response analysis includes both plunging and pitching motions of the blades. In model A, a correction of the angle of attack is applied when the angle of attack exceeds the static stall angle. In model B, a synthesis procedure is used for angles of attack above static stall angles, and the time history effects are accounted for through the Wagner function.

#### 13

#### **GEOSCIENCES**

Includes geosciences (general); earth resources; energy production and conversion; environment pollution; geophysics; meteorology and climatology; and oceanography.

A88-38372#

FOG PERSISTENCE ABOVE SOME AIRPORTS OF THE NORTH-ITALIAN PLAINS [LA PERSISTENZA DELLA NEBBIA SU ALCUNI AEROPORTI DELLE PIANURE DELL'ITALIA SETTENTRIONALE]

ANGELO FANTUZI (Aeronautica Militare Italiana, Servizio Meteorologico, Rome, Italy) Rivista di Meteorologia Aeronautica (ISSN 0035-6328), vol. 47, Apr.-June 1987, p. 117-124. In Italian.

By examining fog events and their persistence during the course of the day, the percent frequencies of fog persistence have been derived for durations of 0 to n hours. The graphic representation of the phenomenon has been also outlined with reference to the most critical period of the year (i.e.,from November to February).

Author

#### A88-38679

## AN INTERACTIVE METHOD FOR MODIFYING NUMERICAL MODEL WIND FORECASTS

DONALD WYLIE, CARL NORTON, and ANN WEICKMANN (Wisconsin, University, Madison) American Meteorological Society, International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology, 2nd, Miami, FL, Jan. 13-17, 1986, Paper. 4 p.

An interactive technique for NASA's Minimum Energy Routing using Interactive Techniques/Advanced Transport Operations System program has been developed. The algorithm has the ability to incorporate hand drawn graphic information into digital grids. It is noted that in the present method the number of lines, their length, and the smoothing function must all be balanced in order to produce the desired effect. The method is illustrated with several wind field corrections.

#### A88-39508

# AIRCRAFT OBSERVATION OF THE SPECIFIC HUMIDITY AND PROCESS OF THE WATER VAPOR TRANSFER IN THE UPPER MIXED BOUNDARY LAYER

SUSUMU YAMAMOTO, MINORU GAMO, and OSAYUKI YOKOYAMA (Ministry of International Trade and Industry, National Research Institute for Pollution and Resources, Tsukuba, Japan) Meteorological Society of Japan, Journal (ISSN 0026-1165), vol. 66, Feb. 1988, p. 141-154. refs

#### A88-39729

## AIRCRAFT NOISE AT THE GRAND CANYON NATIONAL PARK, ARIZONA, USA

ALEX J. SZECSODY IN: NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, State College, PA, June 8-10, 1987. Poughkeepsie, NY, Noise Control Foundation, 1987. p. 527-530. refs

Data from acoustical measurements performed at the Nort Rim, Point Sublime, Grand Canyon National Park, on June 29, 1985 between 1:15 and 2:00 P.M. are presented. Relationships are established between these measurements, urban sound and noise, and a historical reference for the Grand Canyon National Park. It is shown that intrusive noise from helicopters and touring aircraft has raised the ambient sound level from 43(D) to greater than 55 dB(D). Moreover, the hard reflective surfaces of the canyon walls serve to sustain these intrusive noise levels.

N88-22496# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering.

# EXPERIMENTAL COMPARISON OF LIGHTNING SIMULATION TECHNIQUES TO CV-580 AIRBORNE LIGHTNING STRIKE MEASUREMENTS M.S. Thesis

RUDY M. BRAZA Dec. 1987 132 p

(AD-A190576; AFIT/GE/ENG/87D-5) Avail: NTIS HC A07/MF A01 CSCL 04A

Experimental tests on the Lightning Test Cylinder, which further investigated the assessment of lightning simulation techniques conducted by Butters et al., included swept frequency continuous wave (SFCW), current pulse, and shock-excitation. Designed to model the fuselage of an aircraft, the aluminum test cylinder is over ten meters long with a one meter diameter. To test the effects of various aircraft construction materials, the cylinder was constructed with an aperture where various composite and metal panels can be mounted. The research involved determination of the electrical field and magnetic field response transfer functions for each simulation test technique. With these transfer functions, analysis and comparison of the external and internal field responses between the SFCW, current pulse, and shock-excitation tests were made. A major portion of the research was to examine the validity of the linear model for the current pulse simulation technique. In this investigation, transfer functions were derived for various current pulse waveforms. The current waveforms injected into the test cylinder included a 20 kA unipolar, double-exponential pulse and two oscillatory waveforms with peak amplitudes of 20 kA and 100 GRA

#### 15 MATHEMATICAL AND COMPUTER SCIENCES

N88-23346# European Space Agency, Paris (France). STANDARDIZED ICE ACCRETION THICKNESS AS A FUNCTION OF CLOUD PHYSICS PARAMETERS

HANS-EBERHARD HOFFMANN, ROLAND ROTH, and JOHANN DEMMEL (Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Oberpfaffenhofen, West Germany) Mar. 1988 64 p Transl. into ENGLISH of Die Normierte Eisansatzdicke in Abhaengigkeit von Wolkenphysikalischen Parametern (Oberpfaffenhofen, Fed. Republic of Germany, DFVLR), Jan. 1987 64 p Original language document was announced as N88-10464

(ESA-TT-1080; DFVLR-FB-87-08; ETN-88-92561) Avail: NTIS HC A04/MF A01; original German version available from DFVLR, VB-PL-DO, 90 60 58, 5000 Cologne, Fed. Republic of Germany 24.50 DM

Normalized ice accretion thickness was studied using the measurement results of 38 icing research aircraft flights in icing clouds. Normalized ice accretion is the ice accretion thickness on 3 metal cylinders in flow direction, for a true air speed of 125 kt, and a flight path in clouds of 10 NM (i.e., 18.5 km). In the investigated range of liquid water content up to 0.50 g/cum, the normalized ice thickness grows linearly with increasing liquid water content; it is a little larger for cloud particules freezing instantaneously. The thickness is larger for smaller cylinder diameters. In the temperature range between minus 2 and minus 14 C, a difference in temperature has only a little influence, differences in particle phase and particle size distribution have no influence on the normalized ice accretion thickness.

15

#### **MATHEMATICAL AND COMPUTER SCIENCES**

Includes mathematical and computer sciences (general); computer operations and hardware; computer programming and software; computer systems; cybernetics; numerical analysis; statistics and probability; systems analysis; and theoretical mathematics.

#### A88-38178#

### NUMERICAL CALCULATIONS OF A CLASS OF OPTIMAL FLIGHT TRAJECTORIES

PEIDE WANG, TAORUI CUI, and MING HOU (Northwestern Polytechnical University, Xian, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Jan. 1988, p. A19-A25. In Chinese, with abstract in English refs

1988, p. A19-A25. In Chinese, with abstract in English. refs
A simplified direct multiple shooting algorithm is presented in
this paper. The algorithm was developed to solve a class of optimal
trajectory problems with assigned initial state variables, assigned
(or partly assigned) terminal state variables, free terminal time,
and bound constraint both on state and control variables. This
class of problems is first transformed to a Mayer problem with
fixed terminal time; then, a nonlinear programming problem is
formed from the Mayer problem using direct multiple shooting
technique. Satisfactory numerical results are obtained when an
implementation of the presented algorithm is used to minimize
the flight time of a hovercraft and to minimize the total stagnation
point convective heating per unit area. Numerical calculations show
that the algorithm has good convergence and no strict demands
for initial guess in dealing with a flight trajectory problem.

C.D.

#### A88-38179#

### THE MODELLING TECHNIQUE OF THE FLIGHT SYSTEM IN FLIGHT SIMULATOR

ZHENYAN ZHAO (Beijing Institute of Aeronautics and Astronautics, People's Republic of China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893), vol. 9, Jan. 1988, p. A26-A33. In Chinese, with abstract in English. refs

In this paper, the general principles of erecting mathematical models of a flight simulator are presented briefly at first. Then, the mathematical models of aerodynamic coefficients, state of

motion, and atmospheric environment, as well as their method of modeling, are described on the basis of the experience in developing an F-6 flight simulator and with reference to foreign relevant literatures.

#### A88-38725#

### A FLEXIBLE COMPUTER PROGRAM FOR AIRCRAFT FLIGHT TEST PERFORMANCE

HAROLD K. CHENEY (Douglas Aircraft Co., Long Beach, CA) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 213-218. (AIAA PAPER 88-2125)

A flexible general computer program has been developed to determine the flight test performance results from takeoff, climb, cruise, landing, and rejected takeoff test runs. Flexibility is provided by the use of a constants file to provide configuration and detail information applicable to a specific test aircraft. Flag values are used to select the type of performance to be calculated and the various procedures available. The program provides the capability of calculating the test aerodynamic performance for fixed-wing aircraft configurations with one to four engines. Starting with a digital tape containing the measurements recorded during a test, the user is able to obtain final data in tabular, summary page, and plotted formats. The program philosophy, design features, characteristics, and benefits are presented.

#### A88-38746#

## DIAGNOSTIC DESIGN REQUIREMENTS FOR INTEGRATED AVIONIC SUBSYSTEMS

GREGORY E. DAVIS (McDonnell Douglas Helicopter Co., Mesa, AZ) IN: AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 406-409. (AIAA PAPER 88-2171)

This paper discusses the design requirements that should be incorporated into airborne electronics packages when making design changes. Four levels of internal diagnostics will be discussed- background self test, power up Built-In-Test, weapon system level, and peculiar device tests. These test requirements aid in enforcing a top down design approach for the subsystem to meet it's primary duty. The increased use of software controlled microprocessors in avionics designs promotes incorporating these diagnostic requirements. Subsystem checkout can be conducted over the databus without the need for special test equipment, often in less time than required test equipment can go through it's own operational check. Integration and testing of a subsystem containing comprehensive diagnostics is made easier, faster, and more thorough when a device can identify it's own problems realtime.

A88-38765\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

## FLIGHT TEST RESULTS OF A VECTOR-BASED FAILURE DETECTION AND ISOLATION ALGORITHM FOR A REDUNDANT STRAPDOWN INERTIAL MEASUREMENT UNIT

F. R. MORRELL (NASA, Langley Research Center, Hampton, VA), M. L. BAILEY (PRC Kentron International, Hampton, VA), and P. R. MOTYKA (Charles Stark Draper Laboratory, Inc., Cambridge, MA) AIAA, Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988. 11 p. refs (AIAA PAPER 88-2172)

Flight test results of a vector-based fault-tolerant algorithm for a redundant strapdown inertial measurement unit are presented. Because the inertial sensors provide flight-critical information for flight control and navigation, failure detection and isolation is developed in terms of a multi-level structure. Threshold compensation techniques for gyros and accelerometers, developed to enhance the sensitivity of the failure detection process to low-level failures, are presented. Four flight tests, conducted in a commercial transport type environment, were used to determine the ability of the failure detection and isolation algorithm to detect failure signals, such a hard-over, null, or bias shifts. The algorithm

provided timely detection and correct isolation of flight controland low-level failures. The flight tests of the vector-based algorithm demonstrated its capability to provide false alarm free dual fail-operational performance for the skewed array of inertial Author sensors.

#### A88-40707# INTERACTIVE GEOMETRY DEFINITION AND GRID GENERATION FOR APPLIED AERODYNAMICS

H. G. PAGENDARM, E. LAURIEN, and H. SOBIECZKY (DFVLR, Institut fuer theoretische Stroemungsmechanik, Goettingen, Federal Republic of Germany) IN: AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1988, p. 51-57. refs (AIAA PAPER 88-2515)

Euler and Navier-Stokes computational codes become more and more important in applied aerodynamics. For these methods, however, the flowfield and its boundaries have to be discretized very carefully and accurately. We report about a new technique, which allows the definition of surface and far-field geometries and the generation of spatial grids in a very accurate and efficient manner. Our technique uses the enormous capabilities of latest generation personal computers ('workstations') and a fast geometry and grid generator. In our new technique geometries and grids are defined or modified interactively. Thus refinements or improvements of a given discretization can be done much faster and more efficient than with conventional techniques. Our tool works with analytical accuracy. 'Key'-characteristics of the geometry like,e.g., leading and trailing edge of a wing or,e.g., upper and lower crown line of a fuselage are defined by piecewise analytical functions. Grid properties like clustering and curvature parameters of particular families of grid lines are defined likewise. Our method is extremely flexible and applies to the aerodynamics of transport aircraft, space vehicles, wind tunnels and turbomachines. Author

#### N88-22691# Rensselaer Polytechnic Inst., Troy, N.Y. PROBLEMS IN NONLINEAR CONTINUUM DYNAMICS Final **Progress Report**

MARSHALL SLEMROD 1987 9 p (Contract AF AFOSR-0239-85)

(AD-A190538; AFOSR-87-1769TR) Avail: NTIS HC A02/MF A01

The focus of this research was primarily feedback stabilization of distributed parameter systems. The principal investigator derived feedback operators for a general class of distributed systems, which include flexible beams, under the constraint of bounded control. Six papers were published, including Feedback Stabilization in Hilbert Space. Feedback laws are found for control systems governed by partial differential equations. In particular those control systems which give the dynamics of aeroelastic systems have been of interest.

National Aeronautics and Space Administration. N88-23463\*# Langley Research Center, Hampton, Va.

#### A DESCRIPTION OF AN AUTOMATED DATABASE **COMPARISON PROGRAM**

JOHN D. MCMINN, JOHN D. SHAUGHNESSY, and P. DOUGLAS ARBUCKLE May 1988 11 p

(NASA-TM-100609; NAS 1.15:100609) Avail: NTIS HC A03/MF

A01 CSCL 09B

An interactive FORTRAN computer comparison program designed to automatically locate regions of incongruity between two databases is described. The software, guided by user input parameters, incrementally compares the databases and generates plots of these regions in the databases which do not compare within a specified tolerance. Additionally, tools are provided within the software which enable the user to statistically reduce the number of data points in the databases compared. To facilitate the description of these tools, the procedures used to compare two aerodynamic databases for an F-18A fighter aircraft are detailed.

N88-23472\*# Martin Marietta Corp., Denver, Colo. DIGITAL AVIONICS DESIGN AND RELIABILITY ANALYZER Feb. 1981 153 p

(Contract NAS1-15780)

(NASA-CR-181641; NAS 1.26:181641) Avail: NTIS HC A08/MF A01 CSCL 09B

The description and specifications for a digital avionics design and reliability analyzer are given. Its basic function is to provide for the simulation and emulation of the various fault-tolerant digital avionic computer designs that are developed. It has been established that hardware emulation at the gate-level will be utilized. The primary benefit of emulation to reliability analysis is the fact that it provides the capability to model a system at a very detailed level. Emulation allows the direct insertion of faults into the system, rather than waiting for actual hardware failures to occur. This allows for controlled and accelerated testing of system reaction to hardware failures. There is a trade study which leads to the decision to specify a two-machine system, including an emulation computer connected to a general-purpose computer. There is also an evaluation of potential computers to serve as the emulation computer.

National Aeronautics and Space Administration. N88-23519\*# Langley Research Center, Hampton, Va.

#### ACCURACY VERSUS CONVERGENCE RATES FOR A THREE DIMENSIONAL MULTISTAGE EULER CODE Final Report

ELI TURKEL (Tel-Aviv Univ., Israel ) May 1988 21 p Presented at the 16th ICAS Congress, Jerusalem, Israel

(Contract NAS1-18107)

(NASA-CR-181665; ICASE-88-30; NAS 1.26:181665) Avail: NTIS HC A03/MF A01 CSCL 12A

Using a central difference scheme, it is necessary to add an artificial viscosity in order to reach a steady state. This viscosity usually consists of a linear fourth difference to eliminate odd-even oscillations and a nonlinear second difference to suppress oscillations in the neighborhood of steep gradients. There are free constants in these differences. As one increases the artificial viscosity, the high modes are dissipated more and the scheme converges more rapidly. However, this higher level of viscosity smooths the shocks and eliminates other features of the flow. Thus, there is a conflict between the requirements of accuracy and efficiency. Examples are presented for a variety of three-dimensional inviscid solutions over isolated wings.

#### **PHYSICS**

Includes physics (general); acoustics; atomic and molecular physics; nuclear and high-energy physics; optics; plasma physics; solid-state physics; and thermodynamics and statistical physics.

AEROACOUSTICS OF ADVANCED STOVL AIRCRAFT PLUMES K. K. AHUJA and D. A. SPENCER (Lockheed Aeronautical Systems Co., Marietta, GA) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 531-541. refs

(Contract NAS3-23708)

(SAE PAPER 872358)

This paper summarizes a basic and well-controlled experimental study involving flow visualization and noise measurements to define the acoustic and flow fields of single plumes impinging on a simulated ground plane. The flow visualization was made by strobing a laser light source at the discrete frequencies generated by the impingement of the jets and measured by a nearfield microphone. This enabled visualization of instability waves generated by the interaction between the plumes and the sound generated during impingement, and also by dynamic coupling between the two plumes. These data were acquired as a function of distance between the ground and the nozzle exit. Nearfield acoustic data were acquired simultaneously. Data for nozzle diameters of 0.265 in. and 0.4 in. are described. For selected nozzles, effects of exit boundary layer characteristics and nozzle protrusion through a simulated aircraft body are also presented.

Author

## A88-37221\* McDonnell Aircraft Co., St. Louis, Mo. STOVL ACOUSTIC FATIGUE TECHNOLOGIES

DAVID S. GROEN (McDonnell Aircraft Co., Saint Louis, MO) IN: International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 553-562. refs (Contract NAS3-24621) (SAE PAPER 872360)

This paper assesses the state of the art in acoustic fatigue technologies as applied to an advanced supersonic short takeoff and vertical landing (STOVL) aircraft. The topics covered include advanced materials, fatigue, acoustic loads prediction, and stress response prediction. Advanced materials are compared from the standpoints of fatigue resistance and fatigue data availability. State of the art acoustic load prediction techniques are evaluated. Subsonic and supersonic jet noise generation mechanisms, axisymmetric and two-dimensional nozzles, and noise suppression methods are covered. Stress response prediction methods for acoustic, thermal, and maneuvering loads are addressed and the necessity of structural analysis with all three loading types applied simultaneously is assessed.

#### A88-38344

**DEVELOPMENT OF FIBER OPTIC DATA BUS FOR AIRCRAFT** YUTAKA KOMOUCHI (Mitsubishi Heavy Industries, Ltd., Tokyo, Japan) and AKIRA SUEOKA (Mitsubishi Heavy Industries, Ltd., Nagoya Aircraft Works, Japan) Mitsubishi Heavy Industries Technical Review (ISSN 0026-6817), vol. 25, Feb. 1988, p. 57-60.

An account is given of the design, construction, and both ground and flight testing of a star-coupled fiber-optic data bus consisting of an optic coupler, fibers, a connector, and a transmitter/receiver. This system precludes spark/fire hazards and crosstalk problems, while offering very small size and weight for a given capability. The communication protocol for the data bus is of 1 Mbit/sec command response type, and its design attempted to minimize the effect on electronic interfaces as a result of conversion from electrical to fiber-optic buses.

#### A88-38380#

### CALCULATION OF TRANSONIC ROTOR NOISE USING A FREQUENCY DOMAIN FORMULATION

J. PRIEUR (ONERA, Chatillon-sous-Bagneux, France) AIAA Journal (ISSN 0001-1452), vol. 26, Feb. 1988, p. 156-162. Research supported by the Ministere de la Defense. Previously cited in issue 22, p. 3334, Accession no. A86-45402. refs

#### A88-39701

#### NOISE-CON 87; PROCEEDINGS OF THE NATIONAL CONFERENCE ON NOISE CONTROL ENGINEERING, PENNSYLVANIA STATE UNIVERSITY, STATE COLLEGE, JUNE 8-10, 1987

JUNE 8-10, 1987
JIRI TICHY, ED. and SABIH I. HAYEK, ED. (Pennsylvania State University, University Park)
Conference sponsored by the Pennsylvania State University and Institute of Noise Control Engineering. Poughkeepsie, NY, Noise Control Foundation, 1987, 800 p. For individual items see A88-39702 to A88-39731.

The conference presents papers on the control of distributed structures, transfer matrix modeling of geared system vibration, gear dynamic models used in noise analysis, the influence of gear train dynamics on gear noise, an analytical parametric study of the broadband noise from axial-flow fans, and energy radiation and propagation in the nearfield of a vibrating plate. Other topics include the estimation of turbulence effects on sound propagation from low flying aircraft, the diffraction of sound by a smooth ridge, experimental evaluation of active noise control in a thin cylindrical

shell, and distributed sensors and actuators for vibration control in elastic components. Consideration is also given to aircraft noise at the Grand Canyon National Park, reflection tomography imaging, and measurement techniques and results in broad-band generalized nearfield acoustical holography.

K.K.

A88-39708\* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

## COMBUSTION NOISE FROM GAS TURBINE AIRCRAFT ENGINES MEASUREMENT OF FAR-FIELD LEVELS

EUGENE A. KREJSA (NASA, Lewis Research Center, Cleveland, OH) IN: NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, State College, PA, June 8-10, 1987. Poughkeepsie, NY, Noise Control Foundation, 1987, p. 129-134. Previously announced in STAR as N87-17480. refs

Combustion noise can be a significant contributor to total aircraft noise. Measurement of combustion noise is made difficult by the fact that both jet noise and combustion noise exhibit broadband spectra and peak in the same frequency range. Since in-flight reduction of jet noise is greater than that of combustion noise, the latter can be a major contributor to the in-flight noise of an aircraft but will be less evident, and more difficult to measure, under static conditions. Several methods for measuring the far-field combustion noise of aircraft engines are discussed in this paper. These methods make it possible to measure combustion noise levels even in situations where other noise sources, such as jet noise, dominate. Measured far-field combustion noise levels for several turbofan engines are presented. These levels were obtained using a method referred to as three-signal coherence, requiring that fluctuating pressures be measured at two locations within the engine core in addition to the far-field noise measurement. Cross-spectra are used to separate the far-field combustion noise from far-field noise due to other sources. Spectra and directivities are presented. Comparisons with existing combustion noise predictions are made.

#### A88-39712

### ESTIMATION OF TURBULENCE EFFECTS ON SOUND PROPAGATION FROM LOW FLYING AIRCRAFT

RICHARD RASPET, RICHARD K. WOLF, and MICHAEL T. BOBAK (U.S. Army, Construction Engineering Research Laboratory, Champaign, IL) IN: NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, State College, PA, June 8-10, 1987. Poughkeepsie, NY, Noise Control Foundation, 1987, p. 215-220. refs

Conditions under which it is necessary to account for turbulence effects in sound measurements are examined. It is shown how the theory can be modified to incorporate some of the effects of varying scale. It is found that turbulence produces its largest effects when there is strong cancellation under quiet conditions. This produces large effects at low frequencies only when the source is close to the ground and at larger distances. At high frequencies, turbulence produces large effects, even at short ranges.

K.K.

**A88-39722\*** National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

### MECHANISMS OF ACTIVE CONTROL FOR NOISE INSIDE A VIBRATING CYLINDER

HAROLD C. LESTER (NASA, Langley Research Center, Hampton, VA) and CHRIS R. FULLER (Virginia Polytechnic Institute and State University, Blacksburg) IN: NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, State College, PA, June 8-10, 1987. Poughkeepsie, NY, Noise Control Foundation, 1987, p. 371-376.

The active control of propeller-induced noise fields inside a flexible cylinder is studied with attention given to the noise reduction mechanisms inherent in the present coupled acoustic shell model. The active noise control model consists of an infinitely long aluminum cylinder with a radius of 0.4 m and a thickness of 0.001 m. Pressure maps are shown when the two external sources are driven in-phase at a frequency corresponding to Omega = 0.22.

K.K.

Virginia Polytechnic Inst. and State Univ., A88-39725\* Blacksburg.

ACTIVE CONTROL OF SOUND FIELDS IN ELASTIC CYLINDERS BY VIBRATIONAL INPUTS

J. D. JONES and C. R. FULLER (Virginia Polytechnic Institute and State University, Blacksburg) IN: NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, State College, PA, June 8-10, 1987. Poughkeepsie, NY, Noise Control Foundation, 1987, p. 413-418. (Contract NAG1-390)

An experiment is performed to study the mechanisms of active control of sound fields in elastic cylinders via vibrational outputs. In the present method of control, a vibrational force input was used as the secondary control input to reduce the radiated acoustic field. For the frequencies considered, the active vibration technique provided good global reduction of interior sound even though only one actuator was used.

National Aeronautics and Space Administration, N88-22698\*# Washington, D.C.

METHOD AND DEVICE FOR THE DETECTION AND **IDENTIFICATION OF A HELICOPTER** 

Transl, into ENGLISH of HANS SIEBECKER May 1988 22 p German Patent no. DE2655520-C3 (8 Dec. 1986) 7 p Transl. by Scientific Translation Service, Santa Barbara, Calif.

(Contract NASW-4307) (NASA-TT-20251; NAS 1.77:20251) Avail: NTIS HC A03/MF

A01 CSCL 20C

The invention presents a method for detecting and identifying a helicopter based on its characteristic emission of energy in the visual and infrared regions as well as acoustic energy by employing a fire control computer with data storage and a device for targeting Author and observation.

Air Force Occupational and Environmental Health N88-22702# Lab., Brooks AFB, Tex.

NOISE ASSESSMENT OF UNSUPPRESSED TF-34-GE-100A ENGINE AT WARFIELD ANG, BALTIMORE, MARYLAND Final

WINSTON J. SHAFFER, II and JOHN C. ELLIS, II Dec. 1987

(AD-A189966; USAFOEHL-87-164EH0441LNA) Avail: NTIS HC A03/MF A01 CSCL 20A

This report presents the results of noise data measurements of an unsuppressed TF34-GE-100A engine and a community noise survey of the local area around the engine. Three recommendations were made. A two barrier design should be installed as an interim noise control measure. Justification and installation of a noise suppressor, as a long term solution, should be pursued. Day-night sound levels should continue to be monitored until adequate characterization of the airport noise environment is obtained.

**GRA** 

N88-22706# Massachusetts Inst. of Tech., Cambridge. Dept. of Ocean Engineering.

DESCRIBING THE SOURCE CREATED BY TURBULENT FLOW OVER ORIFICES AND LOUVERS M.S. Thesis

GLENN E. CANN Jun. 1987 107 p (Contract N00228-85-G-3262)

(AD-A190254) Avail: NTIS HC A06/MF A01 CSCL 20A

Orifice and louver sound power spectra are investigated, using an intensity probe, at various wind speeds in a low noise, semi-anechoic, subsonic wind tunnel for free stream velocities below 50 meters per second. The radiated noise is created by turbulent flow over various orifice and louver geometries which are flushed mounted into the wall of a long duct. Five orifice samples of rectangular shape and various transverse dimensions as well as four louver samples with multiple rectangular and circular orifices are tested. Also investigated is the effect of the leading and trailing edge angle on the radiated sound power. The scaling laws of the excitation frequencies and the speed/power laws are presented for ratios of the boundary layer thickness to the transverse orifice dimension from 1.01 to 4.29. A detailed theoretical model is developed for rectangular shaped aperture orifices and louvers based on the work by Ffowcs Williams, Nelson, and Corcos.

National Aeronautics and Space Administration. N88-22710\*# Langley Research Center, Hampton, Va.

ADVANCING-SIDE DIRECTIVITY AND RETREATING-SIDE INTERACTIONS OF MODEL ROTOR BLADE-VORTEX INTERACTION NOISE

R. M. MARTIN, W. R. SPLETTSTOESSER, J. W. ELLIOTT, and K.-J. SCHULTZ (Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Brunswick, West Germany ) May 1988 43 p

(NASA-TP-2784; L-16354; NAS 1.60:2784; AVSCOM-TR-87-B-3) Avail: NTIS HC A03/MF A01 CSCL 20A

Acoustic data are presented from a 40 percent scale model of the four-bladed BO-105 helicopter main rotor, tested in a large aerodynamic wind tunnel. Rotor blade-vortex interaction (BVI) noise data in the low-speed flight range were acquired using a traversing in-flow microphone array. Acoustic results presented are used to assess the acoustic far field of BVI noise, to map the directivity and temporal characteristics of BVI impulsive noise, and to show the existence of retreating-side BVI signals. The characterics of the acoustic radiation patterns, which can often be strongly focused, are found to be very dependent on rotor operating condition. The acoustic signals exhibit multiple blade-vortex interactions per blade with broad impulsive content at lower speeds, while at higher speeds, they exhibit fewer interactions per blade, with much sharper, higher amplitude acoustic signals. Moderate-amplitude BVI acoustic signals measured under the aft retreating quadrant of the rotor are shown to originate from the retreating side of the Author

Institut Franco-Allemand de Recherches, St. Louis N88-22713# (France).

ACOUSTIC PROPAGATION IN THE LOW ATMOSPHERE. EXPERIMENTAL STUDY AND MODELING BY THE RADIUS METHOD [PROPAGATION ACOUSTIQUE DANS LA BASSE ATMOSPHERE. ETUDE EXPERIMENTALE ET MODELISATION PAR LA METHODE DES RAYONS]

J. VERMOREL and G. PARMENTIER 21 Nov. 1986 43 p FRENCH; ENGLISH summary

(Contract DRET-85-053)

(ISL-CO-247/86; ETN-88-92018) Avail: NTIS HC A03/MF A01 Acoustic detection is studied with a focus on detection of helicopters. Sound propagation is analyzed as a function of soil and meteorological parameters. Acoustic sensors less sensitive to wind effects were also studied. Propagation calculations were developed, including three dimensional and unsteady computations. The results show the correlation of global acoustic pressure to meteorological parameters and the important perturbations produced by atmospheric turbulence.

N88-23545\*# Cambridge Acoustical Associates, Inc., Mass. STRUCTUREBORNE NOISE MEASUREMENTS ON A SMALL TWIN-ENGINE AIRCRAFT

J. E. COLE, III and K. F. MARTINI Washington NASA 1988 71 p

(Contract NAS1-18020)

(NASA-CR-4137; NAS 1.26:4137; U-1541-349-PT-2) Avail: NTIS HC A04/MF A01 CSCL 20A

Structureborne noise measurements performed on a twin-engine aircraft (Beechcraft Baron) are reported. There are two overall objectives of the test program. The first is to obtain data to support the development of analytical models of the wing and fuselage, while the second is to evaluate effects of structural parameters on cabin noise. Measurements performed include structural and acoustic responses to impact excitation, structural and acoustic loss factors, and modal parameters of the wing. Path alterations include added mass to simulate fuel, variations in torque of bolts joining wing and fuselage, and increased acoustic absorption. Conclusions drawn regarding these measurements are presented. Author

N88-23547\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

ADVANCED TURBOPROP AIRCRAFT FLYOVER NOISE: ANNOYANCE TO COUNTER-ROTATING-PROPELLER CONFIGURATIONS WITH AN EQUAL NUMBER OF BLADES ON EACH ROTOR, PRELIMINARY RESULTS

DAVID A. MCCURDY May 1988 35 p Presented at the 115th Acoustical Society of America Conference, Seattle, Wash., 16-20 May 1988

(NÁSA-TM-100612; NAS 1.15:100612) Avail: NTIS HC A03/MF A01 CSCL 20A

A laboratory experiment was conducted to quantify the annoyance of people to the flyover noise of advanced turboprop aircraft with counter-rotating propellers (CRP) having an equal number of blades on each rotor. The objectives were: to determine the effects of total content on annoyance; and compare annoyance to n x n CRP advanced turboprop aircraft with annoyance to conventional turboprop and jet aircraft. A computer synthesis system was used to generate 27 realistic, time-varying simulations of advanced turboprop takeoff noise in which the tonal content was systematically varied to represent the factorial combinations of nine fundamental frequencies and three tone-to-broadband noise ratios. These advanced turboprop simulations along with recordings of five conventional turboprop takeoffs and five conventional jet takeoffs were presented at three D-weighted sound pressure levels to 64 subjects in an anechoic chamber. Analyses of the subjects' annoyance judgments compare the three aircraft types and examined the effects of the differences in tonal content among the advanced turboprop noises. The annoyance prediction ability of various noise metrics is also examined.

# N88-23548\*# Sikorsky Aircraft, Stratford, Conn. ACOUSTIC CHARACTERISTICS OF 1/20-SCALE MODEL HELICOPTER ROTORS

RAJARAMA K. SHENOY, FRED W. KOHLHEPP, and KENNETH P. LEIGHTON Aug. 1986 144 p

(Contract NAS2-11310)

(NASA-CR-177355; NAS 1.26:177355; SER-510248) Avail: NTIS HC A07/MF A01 CSCL 20A

A wind tunnel test to study the effects of geometric scale on acoustics and to investigate the applicability of very small scale models for the study of acoustic characteristics of helicopter rotors was conducted in the United Technologies Research Center Acoustic Research Tunnel. The results show that the Reynolds number effects significantly alter the Blade-Vortex-Interaction (BVI) Noise characteristics by enhancing the lower frequency content and suppressing the higher frequency content. In the time domain this is observed as an inverted thickness noise impulse rather than the typical positive-negative impulse of BVI noise. At higher advance ratio conditions, in the absence of BVI, the 1/20 scale model acoustic trends with Mach number follow those of larger scale models. However, the 1/20 scale model acoustic trends appear to indicate stall at higher thrust and advance ratio conditions.

#### 17

#### **SOCIAL SCIENCES**

Includes social sciences (general); administration and management; documentation and information science; economics and cost analysis; law and political science; and urban technology and transportation.

N88-22821# Aeritalia S.p.A., Turin (Italy). Gruppo Sistemi Avionica ed Equipaggiamenti.

INFORMATION SYSTEMS FOR QUALITY. EXPERIENCE AT THE NERVIANO AERITALIA PLANT. AVIONIC SYSTEMS AND EQUIPMENT GROUP [SISTEMA INFORMATIVO PER LA QUALITA': ESPERIENZE PRESSO LO STABILIMENTO DI NERVIANO DI AERITALIA]

G. CASATI and R. COLOMBINI 1987 10 p In ITALIAN Presented at Giornata di Studio Indicatori Qualita', Bologna, Italy, 20 Oct. 1987

(ETN-88-92274) Avail: NTIS HC A02/MF A01

The quality information system used at an aerospace industrial plant is described. The goals and the philosophy of the quality organization are discussed. Quality control and quality safety are distinguished. The quality indicators are classified in three categories: product quality indicators, process quality indicators, and project quality indicators. The structure of the quality reports is discussed, including the description of the different rates and indexes used in the report.

#### 19

#### **GENERAL**

## A88-38755# DESIGN, CONSTRUCTION AND FLIGHT TESTING THE SPIRIT

OF ST. LOUIS
WILLIAM IMMENSCHUH (San Diego Aerospace Museum, CA) and
WILLIAM F. CHANA IN: AIAA Flight Test Conference, 4th, San
Diego, CA, May 18-20, 1988, Technical Papers. Washington, DC,
American Institute of Aeronautics and Astronautics, 1988, p.
474-485. refs

(AIAA PAPER 88-2187)

A development and flight testing history is presented for Charles Lindbergh's Spirit of St. Louis. It is noted that the aircraft's 4.3-hour total flight time in San Diego involved no more than 2.6 hours strictly dedicated to obtaining flight test data. On the basis of this data, nevertheless, enough confidence was felt by Lindbergh to proceed with the planned New York-Paris nonstop flight. The flight test results obtained concerned such matters as side-window visibility, recoverability from stalls, aileron-induced roll rates, the adequacy of elevator control for takeoff and landing, top speed, engine reliability, and dynamic longitudinal stability.

#### A88-40548

AEROSPACE PROGRESS AND RESEARCH - THE FORTIETH ANNIVERSARY OF ONERA [RECHERCHES ET PROGRES AEROSPATIAUX - LE QUARANTIEME ANNIVERSAIRE DE L'ONERA]

JEAN CARPENTIER (ONERA, Chatillon-sous-Bagneux, France) Academie des Sciences (Paris), Comptes Rendus, Serie Generale, La Vie des Sciences (ISSN 0762-0969), vol. 4, Sept.-Oct. 1987, p. 405-436. In French.

The current status of ONERA activities in the domains of research, the application of research data to aeronautical construction projects, and the technical assistance given to manufacturers is reviewed. The numerical simulation of the flow

#### **GENERAL** 19

around aircraft and the validation of numerical methods using research wind tunnels is discussed, in addition to the use of industrial wind tunnels for the dvelopment of aircraft, helicopters, and missiles. Propulsion research has centered around the development of turbines, ramjet engines for tactical missiles and hypersonic vehicles, and solid and liquid propellant rocket engines for missiles and launchers. Other topics considered include aircraft materials development, measurement instrumentation, and future plans.

National Aeronautics and Space Administration. N88-22851\*# Lewis Research Center, Cleveland, Ohio.

RESEARCH AND TECHNOLOGY Annual Report, 1987

1987 103 p

(NASA-TM-100172; E-3740; NAS 1.15:100172) Avail: NTIS HC

A06/MF A01 CSCL 05A

The NASA Lewis Research Center's research and technology accomplishments for fiscal year 1987 are summarized. It comprises approximately 100 short articles submitted by staff members of the technical directorates and is organized into four sections: aeronautics, aerospace technology (which includes space communications), space station systems, and computational support. A table of contents by subject was developed to assist the reader in finding articles of special interest.

National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

LANGLEY AEROSPACE TEST HIGHLIGHTS, 1987

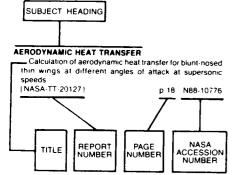
May 1988 114 p

(NASA-TM-100595; NAS 1.15:100595) Avail: NTIS HC A06/MF

A01 CSCL 05D

The role of the Langley Research Center is to perform basic and applied research necessary for the advancement of aeronautics and space flight, to generate new and advanced concepts for the accomplishment of related national goals, and to provide research advice, technological support, and assistance to other NASA installations, other government agencies, and industry. Some of the significant tests which were performed during the calender year 1987 in Langley test facilities are illustrated. Both the broad range of the research and technology activities at Langley and the contributions of this work toward maintaining the U.S. leadership in aeronautic and space research are illustrated.

#### Typical Subject Index Listing



The subject heading is a key to the subject content of the document. The title is used to provide a description of the subject matter. When the title is insufficiently descriptive of document content, a title extension is added, separated from the title by three hyphens. The (NASA or AIAA) accession number and the page number are included in each entry to assist the user in locating the abstract in the abstract section. If applicable, a report number is also included as an aid in identifying the document. Under any one subject heading, the accession numbers are arranged in sequence with the AIAA accession numbers appearing first.

#### A-320 AIRCRAFT

CFRP landing flaps for the Airbus A320

p 474 A88-39416

#### **ACCURACY**

A GPS hover position sensing system

p 503 A88-37390 GPS integrity monitoring for commercial applications using an IRS as a reference p 505 A88-37412 Analysis of a range estimator which uses MLS angle measurements

INASA-CR-1828961 p 507 N88-22884 Accuracy versus convergence rates for a three dimensional multistage Euler code

[NASA-CR-181665] p 554 N88-23519

### **ACOUSTIC FATIGUE**

STOVL acoustic fatigue technologies [SAE PAPER 872360]

p 555 A88-37221 Supersonic jet plume interaction with a flat plate

[SAE PAPER 872361] p 479 A88-37222

#### **ACOUSTIC FREQUENCIES**

Describing the source created by turbulent flow over orifices and louvers [AD-A190254]

p 556 N88-22706

#### **ACOUSTIC MEASUREMENT**

Scale model acoustic testing of counterrotating fans [AIAA PAPER 88-2057] p 523 A88-37947 Combustion noise from gas turbine aircraft engines measurement of far-field levels p 555 A88-39708 Acoustic propagation in the low atmosphere. Experimental study and modeling by the radius method [ISL-CO-247/86] p 556 N88-22713

**ACOUSTIC PROPAGATION** 

Estimation of turbulence effects on sound propagation p 555 A88-39712 from low flying aircraft Acoustic propagation in the low atmosphere Experimental study and modeling by the radius method [ISL-CO-247/86]

#### **ACOUSTIC PROPERTIES**

Acoustic characteristics of 1/20-scale model helicopter rotors [NASA-CR-177355]

**ACOUSTICS** 

p 557 N88-23548

Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557

**ACTIVE CONTROL** 

Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725 Active control and system identification of rotordynamic structure p 551 N88-23230

**ACTS** 

Status and trend in CCV p 528 A88-40526 **ACTUATORS** 

Servo-actuator control for sampled-data feedback disturbance rejection --- helicopters

ESA-TT-10021 p 529 N88-22903 ADAPTIVE CONTROL

AFTI/F-111 Mission Adaptive Wing flight research program

[AIAA PAPER 88-2118] p 511 A88-38719 Flexiwall 3 SO: A second order predictive strategy for rapid wall adjustment in two-dimensional compressible

[NASA-CR-181662] p 498 N88-22018 Model selection for the multiple model adaptive algorithm for in-flight simulation

[AD-A189715] Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive controller

AD-A1898481 n 529 N88-22040 Multiple model parameter adaptive control for in-flight simulation

[AD-A190568] p 537 N88-22044 Aerofoil testing in a self-streamlining flexible walled wind tunnel

[NASA-CR-4128] p 499 N88-22865

ADHESION

Development of a high-temperature resistant (700 F). corrosion-preventive organic coating [AD-A191407] p 543 N88-23009

#### ADIABATIC CONDITIONS

Analysis for high compressible supersonic flow in converging nozzle p 500 N88-22869

#### **AERIAL PHOTOGRAPHY**

The effect of aircraft angular vibrations on the quality of remotely sensed images p 520 A88-41096

#### **AEROACOUSTICS**

Aeroacoustics of advanced STOVL aircraft plumes [SAE PAPER 872358] p 554 A88-37219 Calculation of transonic rotor noise using a frequency domain formulation p 555 A88-38380

NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvania State University, State College, June 8-10, 1987

p 555 A88-39701 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Investigation of aeroacoustic mechanisms by remote

thermal imaging [DE88-002612]

p 538 N88-22046

#### **AERODYNAMIC BALANCE**

A review of Magnetic Suspension and Balance

[AIAA PAPER 88-2008] p 532 A88-37917 Drag measurements on a body of revolution in Langley's 13-inch Magnetic Suspension and Balance System

[AIAA PAPER 88-2010] p 532 A88-37918 Progress towards extreme attitude testing with Magnetic Suspension and Balance Systems

[AIAA PAPER 88-2012] p 532 A88-37920 A forecast of new test capabilities using Magnetic Suspension and Balance Systems

[AIAA PAPER 88-2013] p 532 A88-37921

Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922

**AERODYNAMIC CHARACTERISTICS** 

Hover suckdown and fountain effects --- encountered by V/STOL aircraft

[SAE PAPER 872305] p 477 A88-37177 Effect of ground proximity on characteristics of the STOL aircraft the aerodynamic

[SAE PAPER 872308] p 477 A88-37180 Calculation of external-internal flow fields for

mixed-compression inlets p 479 A88-37353 Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697

Aerodynamic Testing Conference, 15th, San Diego, CA, May 18-20, 1988, Technical Papers p 531 A88-37907 An experimental investigation of the aerodynamic

characteristics of slanted base ogive cylinders using magnetic suspension technology

[AIAA PAPER 88-2011] p 481 A88-37919 The characteristics of asymmetric vortices and side forces on a sharp-nosed body with wing and vertical tail

p 482 A88-38188 A flexible computer program for aircraft flight test

[AIAA PAPER 88-2125] p 553 A88-38725 A real-time aerodynamic analysis system for use in

[AIAA PAPER 88-2128] p 512 A88-38728

Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model
[AIAA PAPER 88-2134] p 512 A88-38731

Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714 Experimental investigation of non-planar sheared

outboard wing planforms [AIAA PAPER 88-2549] D 489 A88-40731

Development of an airfoil of high lift/drag ratio and low moment coefficient for subsonic flow

p 495 A88-40972 Oscillating airfoils: Achievements and conjectures [AD-A1904901

Improvements to tilt rotor performance through passive blade twist control [NASA-TM-1005831 p 548 N88-22434 Design method for laminar fiow control of

two-dimensional airfoils in incompressible flow. Numerical study of LFC design concepts [DE88-751809] p 498 N88-22859

The structure of sonic underexpanded turbulent air jets in still air [AD-A1908561 p 500 N88-22870

Propfan model wind tunnel aeroelastic research p 501 N88-23246 **AERODYNAMIC COEFFICIENTS** 

Cascade lift ratios for radial and semiaxial rotating cascades ascades p 543 A88-37110 Recent developments and engineering applications of the vortex cloud method p 480

Calculated viscous effects on airfoils at transonic [AIAA PAPER 88-2027]

p 481 A88-37931 The modelling technique of the flight system in flight mulator p 553 A88-38179 simulator

#### **AERODYNAMIC CONFIGURATIONS**

The use of optimization technique and through flow analysis for the design of axial flow compressor stages

p 477 A88-37112 Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft (SAE PAPER 8723081

p 477 A88-37180 Aerodynamics of supersonic shapes --- Russian book

p 486 A88-40311 Designs of profiles for cascades [NASA-TT-20161] p 547 N88-22326

Qualification of a water tunnel for force measurements on aeronautical models p 539 N88-23128 An experimental study to determine the flow and the subsonic static and dynamic stability characteristics of aircraft operating at high angles-of-attack

p 518 N88-23129

#### **AERODYNAMIC DRAG**

	ACDODYNAMICS	Aerodynamic investigation by infrared imaging
AERODYNAMIC DRAG	APPlication of empirical and linear methods to VSTOL	(AIAA PAPER 88-2523) p 545 A88-40/13
Development of a real-time aeroperformance analysis	powered-lift aerodynamics	CSCM Navier-Stokes thermal/aerodynamic analysis of
technique for the	SAE PAPER 872341] p 479 A88-37236	hypersonic nozzle flows with slot injection and wall
demonstrator [AIAA PAPER 88-2145] p 512 A88-38738	Numerical senaration models p 480 A88-37653	cooling
Flight tests of external modifications used to reduce blunt	Piezo-electric foils as a means of sensing unsteady	[AIAA PAPER 88-2587] p 493 A88-40756 An overview of hypersonic aerothermodynamics
hase drag	surface forces on flow-around bodies	p 495 A88-41270
14144 PAPER 88-25531 p 494 A88-40763	p 483 A88-38976	Aerothermal tests of quilted dome models on a flat plate
Computational fluid dynamics drag prediction: Hesults	Rotorcraft research at NASA p 475 A88-40552	at a Mach number of 6.5
from the Viscous Transonic Airfoil Workshop	1987 Technical Committee Highlights - The year in	INASA-TP-28041 p 547 N88-22325
[NASA-TM-100095] p 496 N88-22009	review Rotorcraft research and development p 475 A88-40558	Review and assessment of the HOST turbine heat
AERODYNAMIC FORCES	AIAA Applied Aerodynamics Conference, 6th,	transfer program p 526 N88-22431
Development of a block Lanczos algorithm for free	Williamsburg, VA, June 6-8, 1988, Technical Papers	AIR FLOW
vibration analysis of spinning structures p 545 A88-40117	p 487 A88-40701	Development of an airfoil of high lift/drag ratio and low
Unsteady aerodynamic forces at low airfoil pitching	Aerofoil testing in a self-streamlining flexible walled wind	moment coefficient for subsonic flow p 495 A88-40972
	tunnel	•
rates [AIAA PAPER 88-2579] p 492 A88-40748	INASA-CR-41281 p 499 N88-22865	AIR JETS  The structure of sonic underexpanded turbulent air jets
Unsteady aerodynamics of a Wortmann FX-63-137 wing	Aircraft flight dynamics research in past decade	in still air
in a fluctuating wind field	reviewed p 518 N88-23031	[AD-A190856] p 500 N88-22870
[AD-A190128] p 496 N88-22006	Reduced order models for nonlinear aerodynamics	AIR NAVIGATION
influence of unsteady aerodynamic forces on dynamic	p 501 N88-23248	Institute of Navigation, Technical Meeting, 1st, Colorado
response of variable sweep aircraft p 516 N88-22245	Modal forced response of propfans in yawed flow	Springs, CO, Sept. 21-25, 1987, Proceedings
Measurements of aerodynamic forces on unsteadily	p 551 N88-23253	p 502 A88-3/3/6
moving bluff parachute canopies p 549 N88-23137	AEROELASTICITY	Features and capabilities of the DOD standard GPS
Reduced order models for nonlinear aerodynamics	Using frequency-domain methods to identify XV-15	receivers for aircraft and seaborne applications
p 501 N88-23248	aeroelastic modes [SAE PAPER 872385] p 510 A88-37234	p 503 A88-37379
AERODYNAMIC HEATING	A study of aeroelastic stability for the model support	Helicopter terminal approach using differential GPS with
Unsteady aerodynamic heating phenomena in the	system of the National Transonic Facility	vertical-axis enhancement p 503 A88-37397
interaction of shock wave/turbulent boundary layer p 486 A88-40421	(A)AA PAPER 88-20331 p 533 A88-37936	Navigation by satellite - The next step for civil aviation p 506 A88-39375
AERODYNAMIC INTERFERENCE	A study of digital fly-by-wire control system design for	
Wind tunnel interference on unsteady two-dimensional	olastic aircraft D 527 A88-38191	Navigation and performance computer p 519 A88-40518
aerofoil motions in low speed flows p 535 A88-38169	Research at Rensselaer Polytechnic Institute's Center	Current trend of digital map processing
A panel method procedure for interference assessment	of Excellence in rotorcraft technology	p 506 A88-40533
in slotted-wall wind tunnels	p 475 A88-4055/	AIR TRAFFIC CONTROL
(A)AA PAPER 88-2537] p 537 A88-40721	Assessment of transient testing techniques for rotor	Autoland testing - Pushing the (bottom) edge of the
A transonic wind tunnel wall interference prediction	stability testing	envelope
code	[AIAA PAPER 88-2401] p 546 A88-40871	[AIAA PAPER 88-2076] p 511 A88-38703
[AIAA PAPER 88-2538] p 537 A88-40722	The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222	Aircraft accident report: North Star Aviation, Inc., PA-32
Direct assessment of two-dimensional wind-tunnel	rotor blade vibration studies p 515 A88-41222 Shape sensitivity analysis of wing static aeroelastic	RT-300, N39614 and Alameda Aero Club Cessna 172,
interference from measurements on two interfaces (AIAA PAPER 88-2539) p 537 A88-40723	characteristics	N75584, Oakland, California, March 31, 1987
	INASA-TP-28081 p 516 N88-22031	[PB87-910412] p 502 N88-22021
Porous wind tunnel corrections for counterrotation	A numerical model of unsteady, subsonic aeroelastic	AIRBORNE EQUIPMENT
propeller testing LNASA-TM-1008731 p 498 N88-22019	behavior	Formulation of a general technique for predicting pneumatic attenuation errors in airborne pressure sensing
[NASA-TM-100873] p 498 N86-22019 AERODYNAMIC LOADS	[NASA-TM-101126] p 499 N88-22862	
Rotordynamic forces on centrifugal pump impellers	Lewis Structures Technology, 1988. Volume 1: Structural	devices [AIAA PAPER 88-2085] p 518 A88-38707
p 543 A88-3/108	Dynamics	METEOPOD, an airborne system for measurements of
Aerodynamic lag of a close-coupled canard aircraft	[NASA-CP-3003-VOL-1] p 551 N88-23226	mean wind, turbulence, and other meteorological
model at Mach 0.3 to 1.6	Development of aeroelastic analysis methods for	parameters
[AIAA PAPER 88-2030] p 481 A88-37933	turborotors and propfans, including mistuning	[AIAA PAPER 88-2103] p 519 A88-38715
A numerical model of unsteady, subsonic aeroelastic	p 551 N88-23244	An airborne realtime data processing and monitoring
behavior	The 2-D and 3-D time marching transonic potential flow method for propfans p 501 N88-23245	system for research aircraft
[NASA-TM-101126] p 499 N88-22862	moniod for propriate	[AIAA PAPER 88-2165] p 506 A88-38743
The 2-D and 3-D time marching transonic potential flow	Aeroelastic forced response analysis of turbomachinery p 526 N88-23247	Diagnostic design requirements for integrated avionic
method for propfans p 501 N88-23245	Vibration and flutter analysis of the SR-7L large-scale	subsystems
AERODYNAMIC NOISE	propfan p 551 N88-23254	[AIAA PAPER 88-2171] p 553 A88-38746
Optimum porosity for an inclined-hole transonic test section wall treated for edgetone noise reduction	AERONAUTICAL ENGINEERING	AIRBORNE/SPACEBORNE COMPUTERS
[AIAA PAPER 88-2003] p 531 A88-37914	Research and technology	Navigation and performance computer p 519 A88-40518
Calculation of transonic rotor noise using a frequency	(NASA-TM-100172) p 558 N88-22851	Airborne data bases - A quiet revolution
domain formulation p 555 A88-38380	The use of the NRC/NAE water facilities in Canadian	p 506 A88-41089
Structureborne noise measurements on a small	aeronautical research and development	AIRCRAFT
twin-engine aircraft	p 539 N88-23132	Bibliography of icing on aircraft (status 1987)
[NASA-CR-4137] p 556 N88-23545	The ONERA water tunnels test possibilities for flow	[DFVLR-MITT-87-18] p 502 N88-228/6
AERODYNAMIC STABILITY	visualization in aeronautical and Naval domains p 550 N88-23139	AIRCRAFT ACCIDENT INVESTIGATION
Unsteady aerodynamics of a Wortmann FX-63-137 wing	·	Aircraft accident reports, brief format, US civil and foreign
in a fluctuating wind field	AERONAUTICS Langley aerospace test highlights, 1987	aviation, issue number 10 of 1986 accidents
[AD-A190128] p 496 N88-22006		[PB87-916912] p 502 N88-22020
Preliminary airworthiness evaluation of the UH-60A with	[NASA-TM-100595] p 558 N88-22853 AEROSPACE ENGINEERING	Aircraft accident report: North Star Aviation, Inc., PA-32
Advanced Digital Optical Control System (ADOCS)	Aerospace progress and research - The fortieth	RT-300, N39614 and Alameda Aero Club Cessna 172,
[AD-A190674] p 516 N88-22030 The application of linear maximum likelihood estimation	anniversary of ONERA p 557 A88-40548	N75584, Oakland, California, March 31, 1987
of aerodynamic derivatives for the Bell-205 and Bell-206	AEROSPACE ENVIRONMENTS	[PB87-910412] p 502 N88-22021
	An overview of hypersonic aerothermodynamics	Aircraft accident report: Midair collision of US Army
[AD-A191279] p 518 N66-22694 Stability and control methodology for conceptual aircraft	p 495 A88-41270	U-21A, Army 18061 and Sachs Electric Company Piper PA-31-350, N60SE, Independence, Missouri, January 20,
design. Volume 1: Methodology manual	AEROSPACE INDUSTRY	
[AD-A191314] p 530 N88-22906	IR group activities at the Israel Aircraft Industries	1987 [PB88-910401] p 502 N88-22877
AFRODYNAMIC STALLING	p 474 A88-40386	Aircraft accident/incident summary reports: Modena,
Use of dynamically scaled models for studies of the	Aerospace progress and research - The fortieth	Pennsylvania, March 17, 1986; Redwater, Texas, April 4,
high-angle-of-attack behavior of airplanes	anniversary of ONERA p 557 A88-40548	1986
p 535 A88-38692	AEROSPACE PLANES  Fourth-order accurate calculations of the 3-D	[PB88-910403] p 502 N88-22878
Fluid mechanics of dynamic stall. I - Unsteady flow	Today Color accounts	AIRCRAFT ACCIDENTS
concents p 485 A88-39511	compressible boundary layers on aerospace configurations	Aircraft accident report: Midair collision of US Army
Fluid mechanics of dynamic stall. II - Prediction of full scale characteristics p 485 A88-39512	[AIAA PAPER 88-2522] p 487 A88-40712	U-21A, Army 18061 and Sachs Electric Company Piper
scale characteristics p 485 A88-39512 Unsteady aerodynamic forces at low airfoil pitching	National Aero-Space Plane	PA-31-350, N60SE, Independence, Missouri, January 20,
	[AAS PAPER 87-127] p 540 A88-41288	1987
rates [AIAA PAPER 88-2579] p 492 A88-40748	AEROSPACE TECHNOLOGY TRANSFER	[PB88-910401] p 502 N88-22877
Development of aeroelastic analysis methods for	Langley aerospace test highlights, 1987	AIRCRAFT ANTENNAS  A role for fibre optics in antenna measurements
turborotors and propfans, including mistuning	[NASA-TM-100595] p 558 N88-22853	p 544 A88-38116
p 551 N88-23244	AEROTHERMODYNAMICS	AIRCRAFT COMMUNICATION

AIRCRAFT COMMUNICATION
Implementation of aeronautical mobile satellite services
(AMSSs) p 506 A88-40519

Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40314
Thermal state of a turbofan rotor p 545 A88-40317

Application of Navier-Stokes analysis to stall flutter p 530 N88-23249
Stall flutter analysis of propfans p 552 N88-23256

AIDODATT COMMONDATIONS		
AIRCRAFT CONFIGURATIONS	AFTI/F-111 Mission Adaptive Wing flight research	Flight evaluation of an integrated control and display
Quiet Short-Haul Research Aircraft - A summary of flight	program	system for high-precision manual landing flare of
research since 1981	[AIAA PAPER 88-2118] p 511 A88-38719	powered-lift STOL aircraft
[SAE PAPER 872315] p 508 A88-37186	Program review of European Fighter Aircraft	[SAE PAPER 872316] p 508 A88-37187
Some topics of ASKA's flight test results and its future plan	[AIAA PAPER 88-2120] p 511 A88-38721 Diagnostic design requirements for integrated avionic	V/STOL and the Royal Air Force
[SAE PAPER 872317] p 508 A88-37188	subsystems	[SAE PAPER 872319] p 508 A88-37189
Numerical simulation of compressible flow field about	[AIAA PAPER 88-2171] p 553 A88-38746	Helicopter terminal approach using differential GPS with
complete ASKA aircraft configuration	Maintainability - A design parameter	vertical-axis enhancement p 503 A88-37397
[SAE PAPER 872346] p 478 A88-37212	(AIAA PAPER 88-2184) p 474 A88-38753	Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds
Civil applications of high speed rotorcraft and powered	Design, construction and flight testing the Spirit of St.	critical decision point
lift aircraft configurations	Louis	[AIAA PAPER 88-2127] p 511 A88-38727
[SAE PAPER 872372] p 501 A88-37226	[AIAA PAPER 88-2187] p 557 A88-38755	Measurement of multipath propagation of
New structural technologies for the Dornier 328 fuselage p 473 A88-37297	V-22 Osprey - Changing the way man flies p 514 A88-39277	electromagnetic waves in actual airport environments
Flow solution on a dual-block grid around an airplane	Dornier 328 taking shape p 514 A88-39415	p 506 A88-39813
p 479 A88-37355	Technologies for hypersonic flight	AIRCRAFT MAINTENANCE
Flow analysis around aircraft by viscous flow	p 540 A88-39419	Maintainability - A design parameter
computation p 482 A88-38343	Aerospace equipment - Evolution and future problems	[AIAA PAPER 88-2184] p 474 A88-38753
Flow in out-of-plane double S-bends	p 474 A88-40522	Osprey's VSLED - Rewriting the maintenance manual
p 484 A88-39011	Aircraft without airports - Changing the way men fly	vibration, structural life, and engine diagnostics
The numerical simulation of the Navier-Stokes equations	tilt-rotor vehicles technology p 476 A88-40559	system p 474 A88-39325
for an F-16 configuration	Design of low Reynolds number airfoils. I	Development of a flexible and economic helicopter
[AIAA PAPER 88-2507] p 487 A88-40702 Experimental and theoretical study of the effects of wing	[AIAA PAPER 88-2572] p 494 A88-40765 On inverse airfoil design	engine monitoring system
geometry on a supersonic multibody configuration	[AIAA PAPER 88-2573] p 495 A88-41048	[PB88-165147] p 517 N88-22887
[AIAA PAPER 88-2510] p 494 A88-40766	National Aero-Space Plane	Development of a high-temperature resistant (700 F),
Oscillating airfoils: Achievements and conjectures	[AAS PAPER 87-127] p 540 A88-41288	corrosion-preventive organic coating [AD-A191407] p. 543 N88-23009
[AD-A190490] p 496 N88-22008	Trends in Computational Fluid Dynamics (CFD) for	[AD-A191407] p 543 N88-23009 AIRCRAFT MANEUVERS
Trends in Computational Fluid Dynamics (CFD) for	aeronautical 3D steady applications: The Dutch situation	The F-15 STOL and maneuver technology demonstrator
aeronautical 3D steady applications: The Dutch situation	[NLR-MP-86074-U] p 498 N88-22017	(S/MTD) program
[NLR-MP-86074-U] p 498 N88-22017	Activities report in aerospace	[SAE PAPER 872383] p 510 A88-37232
The application of linear maximum likelihood estimation	[ETN-88-91566] p 476 N88-22856	NOTAR - The tail that wags the dog NO TAil Rotor
of aerodynamic derivatives for the Bell-205 and Bell-206	The initial calculation of range and mission fuel during	helicopter p 510 A88-38696
[AD-A191279] p 518 N88-22894 Water facilities in retrospect and prospect: An	conceptual design aircraft design [LR-525] p 517 N88-22889	Effects of maneuver dynamics on drag polars of the
illuminating tool for vehicle design p 539 N88-23126	[LR-525] p 517 N88-22889 Basic design of a flight director system for NAL STOL	X-29A forward-swept-wing aircraft with automatic wing
Flow visualization study of vortex manipulation on fighter	research aircraft	camber control
configurations at high angles of attack	[DE88-751806] p 521 N88-22897	[AIAA PAPER 88-2144] p 527 A88-38737 Helicopter aerobatic flight - The tactical significance
p 549 N88-23130	Stability and control methodology for conceptual aircraft	[AIAA PAPER 88-2190] p 502 A88-38756
AIRCRAFT CONSTRUCTION MATERIALS	design. Volume 1: Methodology manual	AIRCRAFT MODELS
STOVL acoustic fatigue technologies	[AD-A191314] p 530 N88-22906	Large-scale model for experimental wind tunnel
[SAE PAPER 872360] p 555 A88-37221	Water facilities in retrospect and prospect: An	investigations p 531 A88-37298
New structural technologies for the Dornier 328	illuminating tool for vehicle design p 539 N88-23126	Aerodynamic lag of a close-coupled canard aircraft
fuselage p 473 A88-37297	The use of the NRC/NAE water facilities in Canadian	model at Mach 0.3 to 1.6
Large-scale model for experimental wind tunnel investigations p 531 A88-37298	aeronautical research and development	[AIAA PAPER 88-2030] p 481 A88-37933
Almost all composite helicopter p 510 A88-38352	p 539 N88-23132 AIRCRAFT ENGINES	Use of dynamically scaled models for studies of the
Rising to the challenge - Research at AATD	Lift engines - Applied history	high-angle-of-attack behavior of airplanes
p 475 A88-40555	[SAE PAPER 872347] p 522 A88-37213	p 535 A88-38692 Flight testing a V/STOL aircraft to identify a full-envelope
Research at Rensselaer Polytechnic Institute's Center	Gas turbines challenge ceramic technology	aerodynamic model
of Excellence in rotorcraft technology	p 540 A88-37430	[AIAA PAPER 88-2134] p 512 A88-38731
p 475 A88-40557	A survey of the flight testing and evaluation of CF M56	Model selection for the multiple model adaptive
Experimental comparison of lightning simulation	series turbofan	algorithm for in-flight simulation
techniques to CV-580 airborne lightning strike	[AIAA PAPER 88-2078] p 513 A88-38763	[AD-A189715] p 515 N88-22022
measurements [AD-A190576] p.552 N88-22496	Addendum-dedendum type circular-arc gears for	AIRCRAFT NOISE
[AD-A190576] p 552 N88-22496 AIRCRAFT CONTROL	aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280	Combustion noise from gas turbine aircraft engines
Control law design of a CCV airplane	Research as part of the Air Force in aero propulsion	measurement of far-field levels p 555 A88-39708
		Estimation of turbulence effects on sound propagation
p 527 A88-38192	technology (AFRAPT) program	
Design of an integrated control system for flutter margin		from low flying aircraft p 555 A88-39712
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a		from low flying aircraft p 555 A88-39712 Mechanisms of active control for noise inside a vibrating
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics	from low flying aircraft p 555 A88-39712 Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382	from low flying aircraft p 555 A88-39712 Mechanisms of active control for noise inside a vibrating
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park,
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885]  Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405 AIRCRAFT EQUIPMENT	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405 AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405 AIRCRAFT EQUIPMENT	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885]  Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22866 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530  Optical technology application in aircraft	from low flying aircraft p 555 A88-39712 Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725 Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545  Advanced turboprop aircraft flyover noise: Annoyance
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal	from low flying aircraft p 555 A88-39712 Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725 Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906  AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39729  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39729  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique tlying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 87230] p 522 A88-37199	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  AIRCRAFT PARTS
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22866 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  AIRCRAFT PARTS  Development of fiber optic data bus for aircraft
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display Trends and problems of head-up display Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725  Aircraft noise at the Grand Canyon National Park, Arizona, USA  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  AIRCRAFT PARTS
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900 AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133 AIRCRAFT INDUSTRY Activities report in aerospace	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder  Mechanisms of active control for noise inside a vibrating cylinder  p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725 Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612]  P 557 N88-23547  AIRCRAFT PARTS  Development of fiber optic data bus for aircraft p 555 A88-38344  Modern surface protections for aircraft p 551 A88-39417
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display Trends and problems of head-up display Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133  AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder  Mechanisms of active control for noise inside a vibrating cylinder  p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs Aircraft noise at the Grand Canyon National Park, Arizona, USA  p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40753 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547 AIRCRAFT PARTS Development of fiber optic data bus for aircraft p 555 A88-38344 Modern surface protections for aircraft p 541 A88-39417 AIRCRAFT PERFORMANCE
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 [SAE PAPER 872338] p 473 A88-37206	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display Trends and problems of head-up display Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133  AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856  AIRCRAFT INSTRUMENTS	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39712 Active control of sound fields in elastic cylinders by vibrational inputs Active across at the Grand Canyon National Park, Arizona, USA The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-39725 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 555 A88-38344 Modern surface protections for aircraft p 551 A88-39417  AIRCRAFT PERFORMANCE Performance flight testing of a single engine powered
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872338] p 473 A88-37206 Lift engines - Applied history	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900 AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133 AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856 AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook	from low flying aircraft p 555 A88-39712  Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39729  Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39729  Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  AIRCRAFT PARTS  Development of fiber optic data bus for aircraft p 555 A88-38344  Modern surface protections for aircraft p 541 A88-39417  AIRCRAFT PERFORMANCE  Performance flight testing of a single engine powered lift aircraft
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872338] p 473 A88-37206 Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display Trends and problems of head-up display Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133  AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856  AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39712 Active control of sound fields in elastic cylinders by vibrational inputs Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40753 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547 AIRCRAFT PARTS Development of fiber optic data bus for aircraft p 555 A88-38344 Modern surface protections for aircraft p 541 A88-39417  AIRCRAFT PERFORMANCE Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872338] p 473 A88-37206 Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213 STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900 AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133 AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856 AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39712 Active control of sound fields in elastic cylinders by vibrational inputs Active control of sound fields in elastic cylinders by vibrational inputs Active control of sound fields in elastic cylinders by vibrational inputs Active control of sound fields in elastic cylinders by vibrational inputs Active control of sound fields in elastic cylinders by vibrational Profess Aircraft noise at the Grand Canyon National Park, Arizona, USA P 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program P 475 A88-40553 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] [AD-A189966] Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] P 556 N88-23725 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] P 557 N88-23547 AIRCRAFT PARTS Development of fiber optic data bus for aircraft P 551 A88-39417 AIRCRAFT PERFORMANCE Performance protections for aircraft [NASA-TM-10612] P 557 A88-39417 AIRCRAFT PERFORMANCE Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] P 507 A88-37185 Wave drag and high-speed performance of supersonic
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872338] p 473 A88-37206 Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213 STOVL RCS effects on propulsion system design [SAE PAPER 872347] p 522 A88-37214 The RSRA/X-Wing experiment - A status report	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133  AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856  AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 Reflections on the integration of avionics equipment p 519 A88-40517	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39712 Active control of sound fields in elastic cylinders by vibrational inputs Active control of sound fields in elastic cylinders by vibrational inputs Active control of sound fields in elastic cylinders by vibrational inputs p 556 A88-39725 Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] [AD-A189966] [AD-A189966] Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612]  P 557 N88-23547  AIRCRAFT PARTS  Development of fiber optic data bus for aircraft p 541 A88-39417  AIRCRAFT PERFORMANCE Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] P 507 A88-37185 Wave drag and high-speed performance of supersonic STOVL fighter configurations
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 [SAE PAPER 872337] p 473 A88-37206 Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213 STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214 The RSRA/X-Wing experiment - A status report [SAE PAPER 872371] p 479 A88-37225	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133  AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856  AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 Reflections on the integration of avionics equipment p 519 A88-40517  AIRCRAFT LANDING Landing surface characteristics unique to V/STOL	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder  Mechanisms of active control for noise inside a vibrating cylinder  p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs Aircraft noise at the Grand Canyon National Park, Arizona, USA  p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program  p 475 A88-40553 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612]  Development of fiber optic data bus for aircraft p 557 N88-23547  AIRCRAFT PARTS  Development of fiber optic data bus for aircraft p 541 A88-39417  AIRCRAFT PERFORMANCE  Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] Wave drag and high-speed performance of supersonic STOVL fighter configurations [SAE PAPER 872311] p 479 A88-37235
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872338] p 473 A88-37206 Lift engines - Applied history [SAE PAPER 872349] p 522 A88-37214 The RSRA/Wing experiment - A status report [SAE PAPER 872371] p 479 A88-37225 Applying vectored thrust V/STOL experience in	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display P 519 A88-40532 Trends and problems of head-up display P 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900 AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133 AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856 AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 Reflections on the integration of avionics equipment p 519 A88-40517 AIRCRAFT LANDING Landing surface characteristics unique to V/STOL aircraft	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder  Mechanisms of active control for noise inside a vibrating cylinder  p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs Aircraft noise at the Grand Canyon National Park, Arizona, USA  p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40753 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547 AIRCRAFT PARTS Development of fiber optic data bus for aircraft p 554 A88-39417 AIRCRAFT PERFORMANCE Performance flight testing of a single engine powered lift aircraft (SAE PAPER 872314) Wave drag and high-speed performance of supersonic STOVL fighter configurations [SAE PAPER 872311] P 479 A88-37235 NOTAR - The tail that wags the dog NO TAil Rotor
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872337] p 522 A88-37206 Lift engines - Applied history [SAE PAPER 872349] p 522 A88-37213 STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214 The RSRA/X-Wing experiment - A status report [SAE PAPER 872371] p 479 A88-37225 Applying vectored thrust V/STOL experience in supersonic designs	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display Trends and problems of head-up display Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900 AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133 AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856 AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 Reflections on the integration of avionics equipment p 519 A88-40517 AIRCRAFT LANDING Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder  Mechanisms of active control for noise inside a vibrating cylinder  p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs Active control of sound fields in elastic cylinders by vibrational riputs Aircraft noise at the Grand Canyon National Park, Arizona, USA  p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40753 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] [AB-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] [Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] [NASA-TM-100612] [AB-23547 AIRCRAFT PARTS  Development of fiber optic data bus for aircraft p 555 A88-38344 Modern surface protections for aircraft p 5541 A88-39417  AIRCRAFT PERFORMANCE  Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] [SAE PAPER 872314] [SAE PAPER 872311]
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windfunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872337] p 522 A88-37213 STOVL RCS effects on propulsion system design [SAE PAPER 872347] p 522 A88-37214 The RSRA/X-Wing experiment - A status report [SAE PAPER 872371] p 479 A88-37225 Applying vectored thrust V/STOL experience in supersonic designs	[AD-A190336] p 525 N88-22036 Lewis Structural Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display p 519 A88-40534 Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900  AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133  AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856  AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 Reflections on the integration of avionics equipment p 519 A88-40517  AIRCRAFT LANDING Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182 The high technology test bed program - An overview	from low flying aircraft Mechanisms of active control for noise inside a vibrating cylinder  Mechanisms of active control for noise inside a vibrating cylinder  p 555 A88-39722 Active control of sound fields in elastic cylinders by vibrational inputs Aircraft noise at the Grand Canyon National Park, Arizona, USA  p 552 A88-39729 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40753 Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702 Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547 AIRCRAFT PARTS Development of fiber optic data bus for aircraft p 5541 A88-39417 AIRCRAFT PERFORMANCE Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] Vave drag and high-speed performance of supersonic STOVL fighter configurations [SAE PAPER 872311] NOTAR - The tail that wags the dog NO TAil Rotor helicopter AIAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers p 510 A88-38696
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Expanded envelope concepts for aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886 Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891 Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual [AD-A191314] p 530 N88-22906 AIRCRAFT DESIGN A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Flight propulsion control integration for V/STOL aircraft [SAE PAPER 872330] p 522 A88-37199 Advanced tactical transport needs and design implications [SAE PAPER 872337] p 473 A88-37205 VSTOL design implications for tactical transports [SAE PAPER 872337] p 522 A88-37206 Lift engines - Applied history [SAE PAPER 872349] p 522 A88-37213 STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214 The RSRA/X-Wing experiment - A status report [SAE PAPER 872371] p 479 A88-37225 Applying vectored thrust V/STOL experience in supersonic designs	[AD-A190336] p 525 N88-22036 Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Structural analyses of engine wall cooling concepts and materials p 542 N88-22405  AIRCRAFT EQUIPMENT Aerospace equipment - Evolution and future problems p 474 A88-40522 Structure and equipments of the T-2 CCV aircraft p 514 A88-40530 Optical technology application in aircraft p 474 A88-40532 Trends and problems of head-up display Trends and problems of head-up display Basic design studies for the realization of liquid crystal display systems in aircraft [VA-87-001] p 521 N88-22900 AIRCRAFT FUELS Control of an aircraft electric fuel pump drive p 524 A88-39133 AIRCRAFT INDUSTRY Activities report in aerospace [ETN-88-91566] p 476 N88-22856 AIRCRAFT INSTRUMENTS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 Reflections on the integration of avionics equipment p 519 A88-40517 AIRCRAFT LANDING Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182	Mechanisms of active control for noise inside a vibrating cylinder  Mechanisms of active control for noise inside a vibrating cylinder  p 555 A88-39722  Active control of sound fields in elastic cylinders by vibrational inputs  Arizona, USA  p 552 A88-39729  The NASA/AHS Rotorcraft Noise Reduction Program  p 475 A88-40553  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  [AD-A189966]  p 556 N88-22702  Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137]  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612]  P 557 N88-23547  AIRCRAFT PARTS  Development of fiber optic data bus for aircraft  p 541 A88-39417  AIRCRAFT PERFORMANCE  Performance flight testing of a single engine powered lift aircraft  [SAE PAPER 872314]  Wave drag and high-speed performance of supersonic STOVL fighter configurations  [SAE PAPER 872311]  NOTAR - The tail that wags the dog NO TAil Rotor helicopter  p 510 A88-38696  AIAA Flight Test Conference, 4th, San Diego, CA, May

p 511 A88-38721

[SAE PAPER 8/2352]

ATTITUDE (INCLINATION)

Integration of differential GPS with INS for precise position, attitude and azimuth determination p 504 A88-37405

### AIRCRAFT POWER SUPPLIES

A flexible computer program for aircraft flight test	AIRFOIL PROFILES	Expanded envelope concepts for aircraft
performance	An experimental investigation of flowfield about a	control-element failure detection and identification
[AIAA PAPER 88-2125] p 553 A88-38725	multielement airfoil	[NASA-CR-181664] p 507 N88-22886
Performance improvements of an F-15 airplane with an	[AIAA PAPER 88-2035] p 481 A88-37937	ALL-WEATHER LANDING SYSTEMS
integrated engine-flight control system	Wind tunnel interference on unsteady two-dimensional	Autoland testing - Pushing the (bottom) edge of the
[AIAA PAPER 88-2175] p 527 A88-38747	aerofoil motions in low speed flows p 535 A88-38169	envelope
V-22 Osprey - Changing the way man flies	AFTI/F-111 Mission Adaptive Wing flight research	[AIAA PAPER 88-2076] p 511 A88-38703
p 514 A88-39277	program	ALTERNATING CURRENT
Tupolev Backfire p 514 A88-39504	[AIAA PAPER 88-2118] p 511 A88-38719	Advanced capacitor development
Parametric study of supersonic STOVL flight	Wind tunnel investigation of wing-in-ground effects	[AD-A189985] p 546 N88-22276
characteristics	1AIAA PAPER 88-2527 p 488 A88-40716	ALUMINUM ALLOYS
[NASA-CR-177330] p 518 N88-22893	On inverse airfoil design	Elevated-temperature Al alloys for aircraft structure
AIRCRAFT POWER SUPPLIES	[AIAA PAPER 88-2573] p 495 A88-41048	p 541 A88-40486
Power supply for an easily reconfigurable connectorless	On the use of subcycling for solving the compressible	AMPLIFICATION
passenger-aircraft entertainment system	Navier-Stokes equations by operator-splitting and finite	Analysis and design of gain scheduled control
p 513 A88-38800	element methods p 495 A88-41269	systems
AIRCRAFT PRODUCTION	High Reynolds number, low Mach number, steady flow	[NASA-CR-182867] p 529 N88-22904
Activities report in aerospace	field calculations over a NACA 0012 airfoil using	ANALYSIS (MATHEMATICS)
[ETN-88-91566] p 476 N88-22856	Navier-Stokes and interactive boundary layer theory	Analytical sensor redundancy assessment
AIRCRAFT RELIABILITY	[AD-A189871] p 496 N88-22005	[NASA-CR-182892] p 521 N88-22901
Testing new aircraft - Is there an R&M challenge?	Computational fluid dynamics drag prediction: Results	ANECHOIC CHAMBERS
[AIAA PAPER 88-2182] p 474 A88-38752	from the Viscous Transonic Airfoil Workshop	Acoustic characteristics of 1/20-scale model helicopter
Reliability and maintainability evaluation during flight	[NASA-TM-100095] p 496 N88-22009	rotors
	Designs of profiles for cascades	[NASA-CR-177355] p 557 N88-23548
test LAIAA PAPER 88-21851 p 474 A88-38754	[NASA-TT-20161] p 547 N88-22326	ANGLE OF ATTACK
	Short duration flow establishment on a profile in a	The Basic Aerodynamics Research Tunnel - A facility
The role of non-destructive testing in the airworthiness	Water-Ludwieg-Tunnel p 549 N88-23134	dedicated to code validation
certification of civil aircraft composite structures p 545 A88-40175	AIRFOILS	[AIAA PAPER 88-1997] p 531 A88-37910
	The research on adaptive wall wind tunnel in	Progress towards extreme attitude testing with Magnetic
Preliminary airworthiness evaluation of the UH-60A	Northwestern Polytechnical University of China	Suspension and Balance Systems
equipped with the XM-139 VOLCANO mine dispensing	[AIAA PAPER 88-2040] p 534 A88-37942	[AIAA PAPER 88-2012] p 532 A88-37920
system - 510 Nee 22020	Improvements on accuracy and efficiency for calculation	Visualization techniques for studying high angle of attack
[AD-A190604] p 516 N88-22029	improvements on accuracy and emclency for calculation	separated vortical flows
Preliminary airworthiness evaluation of the UH-60A with	of transonic viscous flow around an airfoil p 482 A88-38303	[AIAA PAPER 88-2025] p 544 A88-37930
Advanced Digital Optical Control System (ADOCS)		Use of dynamically scaled models for studies of the
[AD-A190674] p 516 N88-22030	Fluid mechanics of dynamic stall. II - Prediction of full scale characteristics p 485 A88-39512	high-angle-of-attack behavior of airplanes
Airworthiness and flight characteristics test of a ski		p 535 A88-38692
assembly for the UH-60A Black Hawk helicopter	Numerical analysis of multiple element high lift devices	Properties of a half-delta wing vortex
[AD-A191414] p 518 N88-22895	by Navier Stokes equation using implicit TVD finite volume	p 483 A88-38985
AIRCRAFT SAFETY	method   AIAA PAPER 88-2574   D 491 A88-40743	Separation and reattachment near theleading edge of
Radial tires for aircraft? p 510 A88-38353		a thin wing p 486 A88-39967
Soft-ground aircraft arresting systems	Numerical prediction of aerodynamic performance for	An experimental study to determine the flow and the
[AD-A190838] p 539 N88-22912	a low Reynolds number airfoil LAIAA PAPER 88-25751 p 491 A88-40744	subsonic static and dynamic stability characteristics of
AIRCRAFT STABILITY		aircraft operating at high angles-of-attack
Stability flight test verification by modal separation	Unsteady aerodynamic forces at low airfoil pitching	p 518 N88-23129
[AIAA PAPER 88-2129] p 512 A88-38729	rates IAIAA PAPER 88-25791 p 492 A88-40748	Flow visualization study of vortex manipulation on fighter
The effects of torque response and time delay on		configurations at high angles of attack
rotorcraft vertical axis handling qualities	Unsteady viscous-inviscid interaction procedures for	p 549 N88-23130
[AD-A189873] p 515 N88-22023	transonic airfoils using Cartesian grids LAIAA PAPER 88-25911 p 493 A88-40757	Investigation on the movement of vortex burst position
Influence of unsteady aerodynamic forces on dynamic		with dynamically changing angle of attack for a schematic
response of variable sweep aircraft p 516 N88-22245	Design of low Reynolds number airfoils. I	deltawing in a watertunnel with correlation to similar studies
AIRCRAFT STRUCTURES	[AIAA PAPER 88-2572] p 494 A88-40765	in windtunnel p 550 N88-23152
Supersonic jet plume interaction with a flat plate	Development of an airfoil of high lift/drag ratio and low	ANGULAR RESOLUTION
[SAE PAPER 872361] p 479 A88-37222	moment coefficient for subsonic flow	Analysis of a range estimator which uses MLS angle
Some aspects of the reliability analysis of aircraft	p 495 A88-40972	measurements
structures p 544 A88-38181	High Reynolds number, low Mach number, steady flow	[NASA-CR-182896] p 507 N88-22884
Behaviour of damage tolerance of composite aircraft	field calculations over a NACA 0012 airfoil using	ANISOTROPY
structures p 544 A88-38187	Navier-Stokes and interactive boundary layer theory	Improvements to tilt rotor performance through passive
NOTAR - The tail that wags the dog NO TAIl Rotor	[AD-A189871] p 496 N88-22005	blade twist control
helicopter p 510 A88-38696	Oscillating airfoils: Achievements and conjectures (AD-A1904901 p 496 N88-22008	[NASA-TM-100583] p 548 N88-22434
The role of non-destructive testing in the airworthiness	[AD-A190490] p 496 N88-22008	ANTENNA RADIATION PATTERNS
certification of civil aircraft composite structures	Aerofoil testing in a self-streamlining flexible walled wind	A role for fibre optics in antenna measurements
p 545 A88-40175	tunnel [NASA-CR-4128] p 499 N88-22865	p 544 A88-38116
Elevated-temperature Al alloys for aircraft structure		ANTISHIP MISSILES
p 541 A88-40486	An integral equation for the linearized supersonic flow	AQM-127A full scale engineering development Flight
Structure and equipments of the T-2 CCV aircraft	over a wing	Test Program
p 514 A88-40530	[AD-A191408] p 501 N88-22875	[AIAA PAPER 88-2121] p 511 A88-38722
A study of damage tolerance in curved composite	The transonic wind tunnel (TWB) at DFVLR, Brunswick	APPROACH CONTROL
panels	(Federal Republic of Germany)	Computer vision for flight vehicles in landing
AD-A190617] p 541 N88-22092	[DFVLR-MITT-88-01] p 539 N88-22909	
Activities report in aerospace	Reduced order models for nonlinear aerodynamics	
[ETN-88-91566] p 476 N88-22856	p 501 N88-23248	ARCHITECTURE (COMPUTERS)
Design studies of primary aircraft structures in ARALL	Application of Navier-Stokes analysis to stall flutter	Computer vision for flight vehicles in landing approach p 527 A88-39485
laminates	p 530 N88-23249	
[LR-520] p 517 N88-22888	AIRFRAMES	ARRESTING GEAR
Structureborne noise measurements on a small	A study of damage tolerance in curved composite	Soft-ground aircraft arresting systems
twin-engine aircraft	panels	[AD-A190838] p 539 N88-22912
[NASA-CR-4137] p 556 N88-23545	[AD-A190617] p 541 N88-22092	ATMOSPHERIC BOUNDARY LAYER
AIRCRAFT TIRES	Propulsion and airframe aerodynamic interactions of	Aircraft observation of the specific humidity and process
Radial tires for aircraft? p 510 A88-38353	supersonic V/STOL configurations. Volume 4: Summary	of the water vapor transfer in the upper mixed boundary
AIRCRAFT WAKES	[NASA-CR-177343-VOL-4] p 500 N88-22868	layer p 552 A88-39508
Experimental and numerical analysis of the formation	AIRPORTS	Unsteady aerodynamics of a Wortmann FX-63-137 wing
and evolution of streamwise vortices in the plane wake	Fog persistence above some airports of the north-Italian	in a fluctuating wind field
behind a flat plate p 484 A88-39017	plains p 552 A88-38372  Measurement of multipath propagation of	[AD-A190128] p 496 N88-22006
Wake rake studies behind a swept surface, canard		ATMOSPHERIC TEMPERATURE
	electromagnetic waves in actual airport environments	Aircraft observation of the specific humidity and process
aircraft LAIAA PAPER 88-2552] p 489 A88-40732	p 506 A88-39813	of the water vapor transfer in the upper mixed boundary
	Noise assessment of unsuppressed TF-34-GE-100A	layer p 552 A88-39508
Unsteady flow interactions between the wake of an	engine at Warfield ANG, Baltimore, Maryland	ATTACK AIRCRAFT
oscillating airfoil and a stationary trailing airfoil	[AD-A189966] p 556 N88-22702	NASA supersonic STOVL propulsion technology
[AIAA PAPER 88-2581] p 492 A88-40750	ALGORITHMS	program
AIRFOIL OSCILLATIONS Unsteady flow interactions between the wake of an	Development of a block Lanczos algorithm for free vibration analysis of spinning structures	[SAE PAPER 872352] p 523 A88-37215

vibration analysis of spinning structures

p 545 A88-40117

Model selection for the multiple model adaptive algorithm for in-flight simulation

[AD-A189715] p 515 N88-22022

Unsteady flow interactions between the wake of an oscillating airfoil and a stationary trailing airfoil [AIAA PAPER 88-2581] p 492 A88-40750 Analysis of limit cycle flutter of an airfoil in incompressible ow p 546 A88-41219

I AIAA PAPER 88-20121

ATTITUDE CONTROL Progress towards extreme attitude testing with Magnetic Suspension and Balance Systems p 532 A88-37920

Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive

[AD-A189848] p 529 N88-22040 AUGMENTATION

Real-time flight test data distribution and display p 538 N88-22050 INASA-TM-1004241

**AUTOMATIC CONTROL** Effects of maneuver dynamics on drag polars of the

X-29A forward-swept-wing aircraft with automatic wing camber control [AIAA PAPER 88-2144] p 527 A88-38737

The controlled system as a system with nonholonomic constraints - The case of a helicopter p 528 A88-39622

A computational procedure for automated flutter p 530 N88-23250

**AUTOMATIC FLIGHT CONTROL** 

AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-2118] p 511 A88-38719

Status and trend in CCV p 528 A88-40526 Decentralized approach to the design of automatic flight control systems p 528 Preliminary airworthiness evaluation of the UH-60A with

Advanced Digital Optical Control System (ADOCS) [AD-A190674]
AUTOMATIC LANDING CONTROL p 516 N88-22030

Autoland testing - Pushing the (bottom) edge of the envelope

[AIAA PAPER 88-2076] p 511 A88-38703 A new method to confirm category III autoland performance

[AIAA PAPER 88-2126] p 505 A88-38726 **AVIATION METEOROLOGY** 

Fog persistence above some airports of the north-Italian plains p 552 A88-38372 An interactive method for modifying numerical model wind forecasts p 552 A88-38679 AVIONICS

Radio-electronic equipment of aircraft: Handbook ---Russian book p 505 A88-37699 Development of fiber optic data bus for aircraft

p 555 A88-38344 Diagnostic design requirements for integrated avionic subsystems

[AIAA PAPER 88-2171] p 553 A88-38746 Keys to a successful flight test

[AIAA PAPER 88-2174] p.519 A88-38766 Osprey's VSLED - Rewriting the maintenance manual --- vibration, structural life, and engine diagnostics system p 474 A88-39325

Reflections on the integration of avionics equipment p 519 A88-40517 Structure and equipments of the T-2 CCV aircraft

p 514 A88-40530

Optical technology application in aircraft

p 474 A88-40532 Trends and problems of head-up display

p 519 A88-40534 p 545 A88-40535 Flat panel display trends 1987 Technical Committee Highlights - The year in review --- Rotorcraft research and development

Avionics for transport aircraft - Current development p 520 A88-41098 General aviation activity and avionics survey: 1986 data

[AD-A189986] p 476 N88-22003 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure

NLR-MP-86059-U] p 547 N88-22369 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment

IETN-88-922741 p 557 N88-22821 Rapid prototyping of complex avionics system architectures

IETN-88-922751 p 521 N88-22898 The use of rule induction to assist in the diagnosis of avionic circuit board defects

[ETN-88-92077] p 521 N88-22899 Digital avionics design and reliability analyzer

[NASA-CR-181641] p 554 N88-23472 **AXIAL FLOW** 

Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110 p 552 N88-23255 Supersonic axial-flow fan flutter

**AXIAL FLOW TURBINES** Visualisation of the flow at the tip of a high speed axial flow turbine rotor

[AD-A189928] p 546 N88-22300 **AXISYMMETRIC BODIES** 

On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation Pressure-distribution prediction

I AIAA PAPER 88-25131 p 487 A88-40705 AXISYMMETRIC FLOW

Axisymmetric turbulent compressible jet in subsonic p 480 A88-37665 coflow Computation of cascade flow using a finite-flux-element p 485 A88-39488 method Visualisation of the flow at the tip of a high speed axial flow turbine rotor

[AD-A189928] p 546 N88-22300 AZIMUTH

Integration of differential GPS with INS for precise position, attitude and azimuth determination

p 504 A88-37405 Analysis of a range estimator which uses MLS angle

[NASA-CR-182896] p 507 N88-22884

В

**BASE PRESSURE** 

Flight tests of external modifications used to reduce blunt base drag

[AIAA PAPER 88-2553] p 494 A88-40763 BEARINGS

Mode 2 fracture mechanics p 548 N88-22418 Active control and system identification of rotordynamic structure

p 551 N88-23230 BENDING MOMENTS The use of smooth bending moment modes in helicopter

rotor blade vibration studies p 515 A88-41222 **BINOCULAR VISION** 

Optical design criteria for binocular helmet-mounted p 520 A88-41366 displays

**BIRD-AIRCRAFT COLLISIONS** Analytical evaluation of birdstrike against a F-16A laminated canopy

[AIAA PAPER 88-2268] p 514 A88-40868 BITUMENS

Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil p 543 N88-23011

BLADE TIPS

Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863

**BLADE-VORTEX INTERACTION** 

Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710

**BLOWDOWN WIND TUNNELS** Optimum porosity for an inclined-hole transonic test section wall treated for edgetone noise reduction [AIAA PAPER 88-2003]

p 531 A88-37914 An isentropic compression heated Ludwieg tube transient wind tunnel

[AIAA PAPER 88-2019] p 533 A88-37926 The transonic wind tunnel (TWB) at DFVLR, Brunswick (Federal Republic of Germany) [DFVLR-MITT-88-01] p 539 N88-22909

BLOWING

Navier Stokes computation of the flow field over delta wings with spanwise leading edge blowing [AIAA PAPER 88-2558] p 48 p 489 A88-40734

BLUFF BODIES

Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714 Measurements of aerodynamic forces on unsteadily moving bluff parachute canopies p 549 N88-23137 **BLUNT BODIES** 

Flight tests of external modifications used to reduce blunt

base drag [AIAA PAPER 88-2553] p 494 A88-40763 **BODIES OF REVOLUTION** 

Drag measurements on a body of revolution in Langley's 13-inch Magnetic Suspension and Balance System [AIAA PAPER 88-2010] p 532 A88-37918

**BODY-WING AND TAIL CONFIGURATIONS** 

The characteristics of asymmetric vortices and side forces on a sharp-nosed body with wing and vertical tail p 482 A88-38188

**BODY-WING CONFIGURATIONS** 

Application of efficient iteration scheme AF2 to computations of transonic full-potential flows over p 481 A88-38177 wing-body combinations

Transonic Euler calculations of a win configuration using a high-accuracy TVD scheme of a wing-body [AIAA PAPER 88-2547] p 488 A88-40729 Grid generation and flow analyses for wing/body/winglet

[AIAA PAPER 88-2548] p 489 A88-40730 Experimental and theoretical study of the effects of wing

geometry on a supersonic multibody configuration [AIAA PAPER 88-2510] p 494 A88-40766 Transonic Navier-Stokes computations

strake-generated vortex interactions for a fighter-like configuration INASA-TM-1000091 p 497 N88-22010

Laser velocimeter measurements in a wing-fuselage type juncture

[NASA-TM-100588] p 497 N88-22012

**BOEING AIRCRAFT** 

Research and Development at Boeing Helicopters p 476 A88-40560

**BOEING 737 AIRCRAFT** 

A real-time aerodynamic analysis system for use in

[AIAA PAPER 88-2128]

p 512 A88-38728

**BOMBER AIRCRAFT** 

Tupoley Backfire p 514 A88-39504

BOUNDARY LAYER CONTROL Boundary-layer stability analysis of NLF and LFC

experimental data at subsonic and transonic speeds p 483 A88-38925 [SAE PAPER 871859]

Theoretical investigations, and correlative studies for NLF, HLFC, and LFC swept wings at subsonic, transonic and supersonic speeds

[SAE PAPER 871861] p 483 A88-38950 Control of laminar flow around of the wing in free-air conditions

p 495 N88-22004 Modifications to the Langley 8-foot transonic pressure

tunnel for the laminar flow control experiment p 538 N88-22047 [NASA-TM-40321

Design method for laminar flow control of two-dimensional airfoils in incompressible flow. Numerical study of LFC design concepts

IDE88-7518091 p 498 N88-22859

**BOUNDARY LAYER EQUATIONS** 

Three-dimensional unsteady transonic viscous-inviscid interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747

BOUNDARY LAYER FLOW

Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions

[AIAA PAPER 88-2592] p 493 A88-40758 Computational simulation of vortex generator effects on

transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite

cylinder p 495 A88-40970 Boundary-layer and wake measurements on a swept, circulation-control wing

[NASA-TM-89426] p 497 N88-22013 Theoretical investigation of secondary instability of three-dimensional boundary-layer flows with application to the DFVLR-F5 model wing

[DFVLR-FB-87-44] p 547 N88-22330

Nonlinear wave interactions in swept wing flows
NASA-CR-4142] p 550 N88-23160 [NASA-CR-4142] BOUNDARY LAYER SEPARATION

Separation of a supersonic boundary layer ahead of the base of a body p 480 Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions

Separation and reattachment near theleading edge of a thin wing p 486 A88-39967 Experimental investigation of topological structures in p 486 A88-39970

three-dimensional separated flow BOUNDARY LAYER STABILITY

On hypersonic transition testing and prediction [AIAA PAPER 88-2007]

MAA PAPER 88-2007] p 532 A88-37916 Boundary-layer stability analysis of NLF and LFC experimental data at subsonic and transonic speeds p 483 A88-38925 (SAE PAPER 871859)

Oscillating airfoils: Achievements and conjectures [AD-A190490] p 496 N88-22008

Theoretical investigation of secondary instability of three-dimensional boundary-layer flows with application to the DFVLR-F5 model wing [DFVLR-FB-87-44] p 547 N88-22330

**BOUNDARY LAYER TRANSITION** 

Review of transition effects on the problem of dynamic simulation --- of wind tunnel tests p 532 A88-37915

[AIAA PAPER 88-2004] On hypersonic transition testing and prediction [AIAA PAPER 88-2007] p 532 A88-37916 Calculated viscous effects on airfoils at transonic

[AIAA PAPER 88-2027] p 481 A88-37931

#### **BOUNDARY LAYERS**

Techniques used in the F-14 variable-sweep transition	CATHODE RAY TUBES	CODING  On the validation of a code and a turbulence model
flight experiment	Suppressing display cockpit reflections p 515 A88-41364	appropriate to circulation control airfoils
[AIAA PAPER 88-2110] p 513 A88-38762		[NASA-TM-100090] p 499 N88-22864
Control of laminar flow around of the wing in free-air	Optical design criteria for binocular helmet-mounted displays p 520 A88-41366	COLLISION AVOIDANCE
conditions [AD-A187479] p 495 N88-22004	A lightweight innovative Helmet Airborne Display And	Aircraft accident report: Midair collision of US Army
Theoretical investigation of secondary instability of	Sight (HADAS) p 520 A88-41369	U-21A, Army 18061 and Sachs Electric Company Piper
three-dimensional boundary-layer flows with application to	CENTRIFUGAL PUMPS	PA-31-350, N60SE, Independence, Missouri, January 20,
the DFVLR-F5 model wing	Rotordynamic forces on centrifugal pump impellers	1987 [PB88-910401] p 502 N88-22877
[DFVLR-FB-87-44] p 547 N88-22330	p 543 A88-37108	COMBUSTION
BOUNDARY LAYERS	CERAMIC COATINGS	Combustion noise from gas turbine aircraft engines
Heating requirements and nonadiabatic surface effects	Corrosion-resistant thermal barrier coatings	measurement of far-field levels p 555 A88-39708
for a model in the NTF cryogenic wind tunnel [AIAA PAPER 88-2044] p 534 A88-37944	p 540 A88-38315	COMBUSTION CHAMBERS
High Reynolds number, low Mach number, steady flow	Evaluation of ceramic thermal barrier coatings for gas	Development of a variational method for chemical kinetic sensitivity analysis p 541 A88-38490
field calculations over a NACA 0012 airfoil using	turbine engine components	sensitivity analysis p 541 A88-38490 High-temperature combustor liner tests in structural
Navier-Stokes and interactive boundary layer theory	[211/30/3/3/1]	component response test facility p 525 N88-22383
[AD-A189871] p 496 N88-22005	CERAMICS  Gas turbines challenge ceramic technology	Life assessment of combustor liner using unified
BRANCHING (MATHEMATICS)	p 540 A88-37430	constitutive models p 525 N88-22384
Bifurcations in unsteady aerodynamics-implications for	The role of electron microscopy in gas turbine materials	Water flow visualisation of a ramrocket combustion
testing [NASA-TM-100083] p 497 N88-22014	development p 545 A88-40327	chamber p 549 N88-23138
BREADBOARD MODELS	CERTIFICATION	COMBUSTION EFFICIENCY
Nondestructive evaluation of large scale composite	Powered-lift transport aircraft certification criteria	Research as part of the Air Force in aero propulsion
components	status	technology (AFRAPT) program [AD-A190336] p 525 N88-22036
[AD-A190998] p 542 N88-22954	(SAE PAPER 872376) p 501 A88-37227	COMBUSTION STABILITY
BUBBLE TECHNIQUE	CHANNEL FLOW	Investigation of combustion in large vortices
Experimental investigation on rigid hollow hemispherical	Computational study of the unsteady flow due to wakes	[AD-A190406] p 541 N88-22121
parachute model in accelerating and steady flow p 482 A88-38185	passing annual .	COMMAND AND CONTROL
RYPASS RATIO	CHEMICAL REACTIONS Investigation of combustion in large vortices	The controlled system as a system with nonholonomic
Impact of bypass ratio on thrust-to-weight for V/STOL	[AD-A190406] p 541 N88-22121	constraints - The case of a helicopter p 528 A88-39622
[SAE PAPER 872348] p 523 A88-37237	CIRCULAR CYLINDERS	COMMERCIAL AIRCRAFT
	Unsteady nonsimilar laminar compressible	Power supply for an easily reconfigurable connectorless
C	boundary-layer flow over a yawed infinite circular	passenger-aircraft entertainment system
•	cylinder p 495 A88-40970	p 513 A88-38800
CANARD CONFIGURATIONS	CIRCULATION CONTROL AIRFOILS	NASA advanced turboprop research and concept
Aerodynamic lag of a close-coupled canard aircraft	The application of circulation control pneumatic	validation program {NASA-TM-1008911 p 526 N88-22902
model at Mach 0.3 to 1.6	technology to powered-lift STOL aircraft (SAF PAPER 8723351 p 508 A88-37204	[NASA-TM-100891] p 526 N88-22902 COMMUNICATION
[AIAA PAPER 88-2030] p 481 A88-37933	[SAE PAPER 872335] p 508 A88-37204 Boundary-layer and wake measurements on a swept,	Research and technology
Development overview of the T-2 CCV p 528 A88-40527	circulation-control wing	[NASA-TM-100172] p 558 N88-22851
Flowfield study at the propeller disks of a twin pusher,	[NASA-TM-89426] p 497 N88-22013	COMPARISON
canard aircraft	On the validation of a code and a turbulence model	Qualification of a water tunnel for force measurements
[AIAA PAPER 88-2511] p 514 A88-40704	appropriate to circulation control airfoils	on aeronautical models p 539 N88-23128
The effects of canard-wing flow-field interactions on	[NASA-TM-100090] p 499 N88-22864	Investigation on the movement of vortex burst position with dynamically changing angle of attack for a schematic
longitudinal stability, effective dihedral and potential	CIVIL AVIATION	deltawing in a watertunnel with correlation to similar studies
deep-stall trim [AIAA PAPER 88-2514] p 528 A88-40706	Civil applications of high speed rotorcraft and powered	in windtunnel p 550 N88-23152
[AIAA PAPER 88-2514] p 528 A88-40706 Applications of an Euler aerodynamic method to	lift aircraft configurations (SAF PAPER 872372) p 501 A88-37226	A description of an automated database comparison
free-vortex flow simulation	(SAE PAPER 872372) p 501 A88-37226  Radio-electronic equipment of aircraft: Handbook	program
[AIAA PAPER 88-2517] p 487 A88-40708	Russian book p 505 A88-37699	[NASA-TM-100609] p 554 N88-23463
Wake rake studies behind a swept surface, canard	Navigation by satellite - The next step for civil aviation	COMPONENT RELIABILITY  Radial tires for aircraft? p 510 A88-38353
aircraft	p 506 A88-39375	Radial tires for aircraft? p 510 A88-38353 COMPOSITE MATERIALS
[AIAA PAPER 88-2552] p 489 A88-40732	The role of non-destructive testing in the airworthiness	The role of electron microscopy in gas turbine materials
Impingement of orthogonal unsteady vortex structures on trailing aerodynamic surfaces	certification of civil aircraft composite structures	development p 545 A88-40327
[AIAA PAPER 88-2580] p 492 A88-40749	p 545 A88-40175	A study of damage tolerance in curved composite
Unsteady flow interactions between the wake of an	Aerospace equipment - Evolution and future problems	panels
oscillating airfoil and a stationary trailing airfoil	p 474 A88-40522	[AD-A190617] p 541 N88-22092
[AIAA PAPER 88-2581] p 492 A88-40750	General aviation activity and avionics survey: 1986	Structural analyses of engine wall cooling concepts and materials p 542 N88-22405
CANOPIES  Analytical evaluation of birdstrike against a F-16A	data [AD-A189986] p 476 N88-22003	materials p 542 N88-22405 Towards a damage tolerance philosophy for composite
	Aircraft accident reports, brief format, US civil and foreign	materials and structures
laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868	aviation, issue number 10 of 1986 accidents	[NASA-TM-100548] p 542 N88-22949
Measurements of aerodynamic forces on unsteadily	[PB87-916912] p 502 N88-22020	Nondestructive evaluation of large scale composite
moving bluff parachute canopies p 549 N88-23137	Activities report of Lufthansa	components
CAPACITORS	[ISSN-0176-5086] p 476 N88-22855	[AD-A190998] p 542 N88-22954
Advanced capacitor development  IAD-A1899851 p 546 N88-22276	CLIMBING FLIGHT	COMPOSITE STRUCTURES  Behaviour of damage tolerance of composite aircraft
[AD-A189985] p 546 N88-22276  CARBON FIBER REINFORCED PLASTICS	Analysis of performance measurement results of	structures p 544 A88-38187
CARBON FIDER REINFORCED FEASILIES	propeller aircraft. I - Flight performance	The role of non-destructive testing in the airworthiness
CERR landing flans for the Airbus A320	5 514 ARR-39481	
CFRP landing flaps for the Airbus A320	p 514 A88-39481 Applyeis of performance measurement results of aircraft.	certification of civil aircraft composite structures
CFRP landing flaps for the Airbus A320 p 474 A88-39416	Analysis of performance measurement results of aircraft.	certification of civil aircraft composite structures p 545 A88-40175
CFRP landing flaps for the Airbus A320 p 474 A88-39416  Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations		certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite
CFRP landing flaps for the Airbus A320 p 474 A88-39416  Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175 CARBON-CARBON COMPOSITES	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION Standardized ice accretion thickness as a function of cloud physics parameters [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS Bibliography of icing on aircraft (status 1987)	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION Standardized ice accretion thickness as a function of cloud physics parameters [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS Bibliography of icing on aircraft (status 1987) [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW Cascade lift ratios for radial and semiaxial rotating	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW Cascade lift ratios for radial and semiaxial rotating cascades Simulation of transonic flow in radial compressors	Analysis of performance measurement results of aircraft.  II - Flight performance p 5 14 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949
CFRP landing flaps for the Airbus A320 p 474 A88-39416  Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174  The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES  The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Simulation of transonic flow in radial compressors p 480 A88-37356	Analysis of performance measurement results of aircraft.  II - Flight performance p 5 14 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal superalloys p 542 N88-22427	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite components [AD-A190998] p 542 N88-22954 COMPRESSIBLE BOUNDARY LAYER
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW Cascade lift ratios for radial and semiaxial rotating cascades Simulation of transonic flow in radial compressors	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal superalloys p 542 N88-22427	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite components [AD-A190998] p 542 N88-22954 COMPRESSIBLE BOUNDARY LAYER Fourth-order accurate calculations of the 3-D
CFRP landing flaps for the Airbus A320 p 474 A88-39416  Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174  The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES  The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Simulation of transonic flow in radial compressors p 480 A88-37356  Computational study of the unsteady flow due to wakes	Analysis of performance measurement results of aircraft.  II - Flight performance p 5 14 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal superalloys p 542 N88-22427  COCKPITS  Suppressing display cockpit reflections  p 515 A88-41364	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite components [AD-A190988] p 542 N88-22954 COMPRESSIBLE BOUNDARY LAYER Fourth-order accurate calculations of the 3-D compressible boundary layers on aerospace
CFRP landing flaps for the Airbus A320 p 474 A88-39416  Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174  The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES  The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Simulation of transonic flow in radial compressors p 480 A88-37356  Computational study of the unsteady flow due to wakes passing through a channel p 483 A88-38984	Analysis of performance measurement results of aircraft.  II - Flight performance p 514 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal superalloys  COCKPITS  Suppressing display cockpit reflections  p 515 A88-41364  A lightweight innovative Helmet Airborne Display And	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite components [AD-A190998] p 542 N88-22954  COMPRESSIBLE BOUNDARY LAYER Fourth-order accurate calculations of the 3-D compressible boundary layers on aerospace configurations
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110 Simulation of transonic flow in radial compressors p 480 A88-37356 Computational study of the unsteady flow due to wakes passing through a channel p 483 A88-38984 Computation of cascade flow using a finite-flux-element method p 485 A88-39488 Mixed direct-inverse problem of transonic cascade	Analysis of performance measurement results of aircraft.  II - Flight performance p 5 14 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal superalloys  COCKPITS  Suppressing display cockpit reflections  p 515 A88-41364  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite components [AD-A190998] p 542 N88-22954  COMPRESSIBLE BOUNDARY LAYER Fourth-order accurate calculations of the 3-D compressible boundary layers on aerospace configurations [AIAA PAPER 88-2522] p 487 A88-40712
CFRP landing flaps for the Airbus A320 p 474 A88-39416  Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174  The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES  The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Simulation of transonic flow in radial compressors p 480 A88-37356  Computational study of the unsteady flow due to wakes passing through a channel p 483 A88-3984  Computation of cascade flow using a finite-flux-element method p 485 A88-39488	Analysis of performance measurement results of aircraft.  II - Flight performance p 5 14 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal superalloys  COKPITS  Suppressing display cockpit reflections  p 515 A88-41364  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  Geometric modeling of flight information for graphical	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite components [AD-A190988] p 542 N88-22954 COMPRESSIBLE BOUNDARY LAYER Fourth-order accurate calculations of the 3-D compressible boundary layers on aerospace configurations [AIAA PAPER 88-2522] p 487 A88-40712 Unsteady nonsimilar laminar compressible
CFRP landing flaps for the Airbus A320 p 474 A88-39416 Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 The role of non-destructive testing in the airworthiness certification of civil aircraft composite structures p 545 A88-40175  CARBON-CARBON COMPOSITES The role of electron microscopy in gas turbine materials development p 545 A88-40327  CASCADE FLOW Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110 Simulation of transonic flow in radial compressors p 480 A88-37356 Computational study of the unsteady flow due to wakes passing through a channel p 483 A88-38984 Computation of cascade flow using a finite-flux-element method p 485 A88-39488 Mixed direct-inverse problem of transonic cascade	Analysis of performance measurement results of aircraft.  II - Flight performance p 5 14 A88-40575  CLOUD GLACIATION  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  CLOUD PHYSICS  Bibliography of icing on aircraft (status 1987)  [DFVLR-MITT-87-18] p 502 N88-22876  Standardized ice accretion thickness as a function of cloud physics parameters  [ESA-TT-1080] p 553 N88-23346  COATINGS  Fatigue damage modeling for coated single crystal superalloys  COCKPITS  Suppressing display cockpit reflections  p 515 A88-41364  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369	certification of civil aircraft composite structures p 545 A88-40175 A study of damage tolerance in curved composite panels [AD-A190617] p 541 N88-22092 Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496 Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949 Nondestructive evaluation of large scale composite components [AD-A190998] p 542 N88-22954  COMPRESSIBLE BOUNDARY LAYER Fourth-order accurate calculations of the 3-D compressible boundary layers on aerospace configurations [AIAA PAPER 88-2522] p 487 A88-40712

COMPRESSIBLE FLOW		
COMPRESSIBLE FLOW  Numerical simulation of compressible flow field about	A method to increase the accuracy of vortical flow	COMPUTER AIDED MAPPING
complete ASKA aircraft configuration	simulations [AIAA PAPER 88-2562] p 490 A88-40736	Current trend of digital map processing p 506 A88-40533
[SAE PAPER 872346] p 478 A88-37212	Computational validation of a parabolized Navier-Stokes	COMPUTER GRAPHICS
Flow solution on a dual-block grid around an airplane	solver on a sharp-nose cone at hypersonic speeds	Development of an interactive real-time graphics system
p 479 A88-37355 Axisymmetric turbulent compressible jet in subsonic	[AIAA PAPER 88-2566] p 490 A88-40739 Numerical analysis of multiple element high lift devices	for the display of vehicle space positioning
coflow p 480 A88-37665	by Navier Stokes equation using implicit TVD finite volume	[AIAA PAPER 88-2167] p 536 A88-38744
On inverse airfoil design	method	Effects of update and refresh rates on flight simulation visual displays
[AIAA PAPER 88-2573] p 495 A88-41048	[AIAA PAPER 88-2574] p 491 A88-40743	[NASA-TM-100415] p 516 N88-22033
On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite	Numerical prediction of aerodynamic performance for a low Reynolds number airfoil	Geometric modeling of flight information for graphical
element methods p 495 A88-41269	[AIAA PAPER 88-2575] p 491 A88-40744	cockpit display [AD-A190484] p 537 N88-22043
Flexiwall 3 SO: A second order predictive strategy for	Three-dimensional unsteady transonic viscous-inviscid	[AD-A190484] p 537 N88-22043 COMPUTER PROGRAMS
rapid wall adjustment in two-dimensional compressible	interaction using the Euler and boundary-layer equations	A flexible computer program for aircraft flight test
flow [NASA-CR-181662] p 498 N88-22018	[AIAA PAPER 88-2578] p 491 A88-40747 An upwind differencing scheme for the time-accurate	performance
Turbulent reacting flows and supersonic combustion	incompressible Navier-Stokes equations	[AIAA PAPER 88-2125] p 553 A88-38725 The composite blade structural analyzer (COBSTRAN)
[AD-A189690] p 541 N88-22115	[AIAA PAPER 88-2583] p 492 A88-40752	p 525 N88-22390
Theoretical model and numerical solution for	Application of Navier-Stokes analysis to predict the	Specialty three-dimensional finite element analysis
compressible viscous vortex cores p 498 N88-22243 Analysis for high compressible supersonic flow in	internal performance of thrust vectoring two-dimensional convergent-divergent nozzles	codes p 548 N88-22393
converging nozzle	[AIAA PAPER 88-2586] p 493 A88-40755	MHOST: An efficient finite element program for inelastic analysis of solids and structures p 525 N88-22394
[IPPJ-860] p 500 N88-22869	CSCM Navier-Stokes thermal/aerodynamic analysis of	analysis of solids and structures p 525 N88-22394  Computational structural mechanics for engine
COMPRESSION WAVES	hypersonic nozzle flows with slot injection and wall	structures p 525 N88-22399
An isentropic compression heated Ludwieg tube transient wind tunnel	cooling [AIAA PAPER 88-2587] p 493 A88-40756	Computerized life and reliability modelling for turboprop
[AIAA PAPER 88-2019] p 533 A88-37926	Calculations of three-dimensional flows using the	transmissions
COMPUTATION	isenthalpic Euler equations with implicit flux-vector	[NASA-TM-100918] p 551 N88-23220 Vibration and flutter analysis of the SR-7L large-scale
A computational procedure for automated flutter	splitting	propfan p 551 N88-23254
analysis p 530 N88-23250  COMPUTATIONAL FLUID DYNAMICS	[AIAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a	Supersonic axial-flow fan flutter p 552 N88-23255
The use of optimization technique and through flow	Navier-Stokes computation of flow around a round-edged double-delta wing	COMPUTER TECHNIQUES
analysis for the design of axial flow compressor stages	[AIAA PAPER 88-2560] p 494 A88-40767	World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986, Proceedings
p 477 A88-37112	Computational simulation of vortex generator effects on	p 544 A88-37351
Numerical investigation of a jet in ground effect with a crossflow	transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771	An interactive method for modifying numerical model
[SAE PAPER 872344] p 478 A88-37210	[AIAA PAPER 88-2590] p 495 A88-40771 On the use of subcycling for solving the compressible	wind forecasts p 552 A88-38679
Application of empirical and linear methods to VSTOL	Navier-Stokes equations by operator-splitting and finite	Lewis Structures Technology, 1988. Volume 1: Structural Dynamics
powered-lift aerodynamics	element methods p 495 A88-41269	[NASA-CP-3003-VOL-1] p 551 N88-23226
[SAE PAPER 872341] p 479 A88-37236 World Congress on Computational Mechanics, 1st,	Computational fluid dynamics drag prediction: Results from the Viscous Transonic Airfoil Workshop	COMPUTER VISION
Austin, TX, Sept. 22-26, 1986, Proceedings	[NASA-TM-100095] p 496 N88-22009	Computer vision for flight vehicles in landing
p 544 A88-37351	Trends in Computational Fluid Dynamics (CFD) for	approach p 527 A88-39485 Current trend of digital map processing
Calculation of external-internal flow fields for	aeronautical 3D steady applications: The Dutch situation	p 506 A88-40533
mixed-compression inlets p 479 A88-37353	[NLR-MP-86074-U] p 498 N88-22017	COMPUTERIZED SIMULATION
Recent developments and engineering applications of the vortex cloud method p 480 A88-37358	Theoretical model and numerical solution for compressible viscous vortex cores p 498 N88-22243	Simulation of transonic flow in radial compressors
A comparison of numerical algorithms for unsteady	Mixed direct-inverse problem of transonic cascade	p 480 A88-37356 Computer simulation of turbulent jets and wakes
transonic flow p 480 A88-37360	p 498 N88-22244	p 544 A88-37661
A plan for coupling wind tunnel testing with CFD techniques	A panel method based on velocity potential to compute	The use of a computer model to investigate design
[AIAA PAPER 88-1996] p 531 A88-37909	harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290	compatibility between the QF-4 aircraft and the
The Basic Aerodynamics Research Tunnel - A facility	Theoretical investigation of secondary instability of	AQM-127A [AIAA PAPER 88-2143] p 512 A88-38736
dedicated to code validation	three-dimensional boundary-layer flows with application to	[AIAA PAPER 88-2143] p 512 A88-38736 Computational study of the unsteady flow due to wakes
[AIAA PAPER 88-1997] p 531 A88-37910	the DFVLR-F5 model wing	passing through a channel p 483 A88-38984
Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil	[DFVLR-FB-87-44] p 547 N88-22330 A multilifting line method and its application in design	Development and evaluation of an airplane fuel tank
p 482 A88-38303	and analysis of nonplanar wing configurations	ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions
Numerical study of the skin friction on a spheroid at	[DFVLR-FB-87-51] p 499 N88-22860	[AD-A190408] p 515 N88-22025
incidence p 482 A88-38376	La Recherche Aerospatiale, bimonthly bulletin, number	Linear state space modeling of a turbofan engine
Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate	1987-3, 238/May-June [ESA-TT-1075] p 550 N88-23161	[AD-A190110] p 524 N88-22035
Reynolds numbers p 483 A88-38847	Aeroelastic forced response analysis of	Advanced turboprop aircraft flyover noise: Annoyance
Piezo-electric foils as a means of sensing unsteady	turbomachinery p 526 N88-23247	to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results
surface forces on flow-around bodies	COMPUTATIONAL GRIDS	[NASA-TM-100612] p 557 N88-23547
p 483 A88-38976 Experimental and numerical analysis of the formation	Flow solution on a dual-block grid around an airplane p 479 A88-37355	CONDENSING
and evolution of streamwise vortices in the plane wake	Simulation of transonic flow in radial compressors	Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990
behind a flat plate p 484 A88-39017	p 480 A88-37356	CONFERENCES
The calculation of the flow through a two-dimensional faired diffuser p 485 A88-39030	Application of efficient iteration scheme AF2 to computations of transonic full-potential flows over	International Powered Lift Conference and Exposition,
Comparison of Euler and Navier-Stokes solutions for	wing-body combinations p 481 A88-38177	Santa Clara, CA, Dec. 7-10, 1987, Proceedings
vortex flow over a delta wing p 485 A88-39278	Flow analysis around aircraft by viscous flow	[SAE P-203] p 473 A88-37176 World Congress on Computational Mechanics, 1st,
Computation of cascade flow using a finite-flux-element	computation p 482 A88-38343	Austin, TX, Sept. 22-26, 1986, Proceedings
method p 485 A88-39488 Fluid mechanics of dynamic stall. II - Prediction of full	Interactive geometry definition and grid generation for	p 544 A88-37351
scale characteristics p 485 A88-39512	applied aerodynamics [AIAA PAPER 88-2515] p 554 A88-40707	Institute of Navigation, Technical Meeting, 1st, Colorado
Flow visualization and pressure distributions for an	[AIAA PAPER 88-2515] p 554 A88-40707 Grid generation and flow analyses for wing/body/winglet	Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-37376
all-body hypersonic aircraft p 487 A88-40601	configurations	Aerodynamic Testing Conference, 15th, San Diego, CA.
Interactive geometry definition and grid generation for applied aerodynamics	[AIAA PAPER 88-2548] p 489 A88-40730	May 18-20, 1988, Technical Papers p 531 A88-37907
[AIAA PAPER 88-2515] p 554 A88-40707	A method to increase the accuracy of vortical flow	AIAA Flight Test Conference, 4th, San Diego, CA, May
Optimizing advanced propeller designs by	Simulations	18-20, 1988, Technical Papers p 510 A88-38701 NOISE-CON 87; Proceedings of the National
simultaneously updating flow variables and design	[AIAA PAPER 88-2562] p 490 A88-40736  COMPUTER AIDED DESIGN	Conference on Noise Control Engineering, Pennsylvania
parameters [AIAA PAPER 88-2532] p 488 A88-40718	OUMPOIGN AIDED DESIGN	State University State Callege Land 4007
[AIAA PAPER 88-2532] p 488 A88-40718 A transonic wind tunnel wall interference prediction		State University, State College, June 8-10, 1987
	The role of electron microscopy in gas turbine materials development p 545 A88-40327	p 555 A88-39701
code	The role of electron microscopy in gas turbine materials development p 545 A88-40327 An integrated approach to helmet display system	p 555 A88-39701 AIAA Applied Aerodynamics Conference, 6th,
code [AIAA PAPER 88-2538] p 537 A88-40722	The role of electron microscopy in gas turbine materials development p. 545 A88-40327 An integrated approach to helmet display system design p. 520 A88-41368	p 555 A88-39701 AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers
code [AIAA PAPER 88-2538] p 537 A88-40722 Direct assessment of two-dimensional wind-tunnel	The role of electron microscopy in gas turbine materials development p 545 A88-40327 An integrated approach to helmet display system design p 520 A88-41368 Reliability analysis within a Computer Aided Engineering	AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers p 487 A88-40701 Display system optics; Proceedings of the Meeting,
code [AIAA PAPER 88-2538] p 537 A88-40722 Direct assessment of two-dimensional wind-tunnel interference from measurements on two interfaces	The role of electron microscopy in gas turbine materials development p 545 A88-40327  An integrated approach to helmet display system design p 520 A88-41368  Reliability analysis within a Computer Aided Engineering (CAE) infrastructure	AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers p 487 A88-40701 Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987
code [AlAA PAPER 88-2538] p 537 A88-40722 Direct assessment of two-dimensional wind-tunnel interference from measurements on two interfaces [AlAA PAPER 88-2539] p 537 A88-40723 Transonic Euler calculations of a wing-body	The role of electron microscopy in gas turbine materials development p 545 A88-40327  An integrated approach to helmet display system design p 520 A88-41368  Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p 547 N88-22369	AIAA Applied Aerodynamics Donatemence, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987  [SPIE-778]  p 555 A88-39701 Contended Papers p 487 A88-40701 Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987  [SPIE-778]  p 520 A88-41361
code [AlAA PAPER 88-2538] p 537 A88-40722 Direct assessment of two-dimensional wind-tunnel interference from measurements on two interfaces [AlAA PAPER 88-2539] p 537 A88-40723	The role of electron microscopy in gas turbine materials development p 545 A88-40327  An integrated approach to helmet display system design p 520 A88-41368  Reliability analysis within a Computer Aided Engineering (CAE) infrastructure	AIAA Applied Aerodynamics Conference, 6th, Williamsburg, VA, June 6-8, 1988, Technical Papers p 487 A88-40701 Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987

p 538 N88-22907

Time-Of-Flight

measurements of crack depths in an acceleration reservoir

Ultrasonic

of a high velocity research gun [DE88-006644]

PNS calculations of hypersonic transitional flow over

**CONICAL FLOW** 

cones

cones [AIAA PAPER 88-2565] p 490 A88-40738	CONTROL THEORY	[DE88-006644] p 538 N88-22907
CONSTITUTIVE EQUATIONS	Control law design of a CCV airplane	CRACKING (CHEMICAL ENGINEERING)
Life assessment of combustor liner using unified	p 527 A88-38192	Turbine fuels from tar sands bitumen and heavy oil.
constitutive models p 525 N88-22384	The controlled system as a system with nonholonomic	Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil
CONSTRAINTS	constraints - The case of a helicopter	[AD-A190120] p 543 N88-23011
Minimum weight design of rotorcraft blades with multiple	p 528 A88-39622	CRASH LANDING
frequency and stress constraints	Model selection for the multiple model adaptive	Special report on Bell ACAP full-scale aircraft crash
[NASA-TM-100569] p 517 N88-22892	algorithm for in-flight simulation	test
CONTINUUM MECHANICS Problems in nonlinear continuum dynamics	[AD-A189715] p 515 N88-22022	(SAE PAPER 872362) p 509 A88-37223
[AD-A190538] p 554 N88-22691	Multivariable control law design for the AFTI/F-16 with	An analytical method for the ditching analysis of an
CONTRACTION	a failed control surface using a parameter-adaptive	airborne vehicle
Contraction design for small low-speed wind tunnels	controller [AD-A189848] p 529 N88-22040	[AIAA PAPER 88-2521] p 514 A88-40711
[NASA-CR-182747] p 537 N88-22045	(7,5 71,555 75)	CRASHES  KRASH parametric sensitivity study: Transport category
CONTROL CONFIGURED VEHICLES	CONTROLLABILITY  The effects of torque response and time delay on	airplanes
Control law design of a CCV airplane	rotorcraft vertical axis handling qualities	[AD-A189962] p 515 N88-22024
p 527 A88-38192	[AD-A189873] p 515 N88-22023	CRASHWORTHINESS
Status and trend in CCV p 528 A88-40526	Preliminary airworthiness evaluation of the UH-60A with	Special report on Bell ACAP full-scale aircraft crash
Development overview of the T-2 CCV p 528 A88-40527	Advanced Digital Optical Control System (ADOCS)	test
FBW system and control law of the T-2 CCV	[AD-A190674] p 516 N88-22030	[SAE PAPER 872362] p 509 A88-37223
p 528 A88-40528	An investigation of the ability to recover from transients	Behaviour of damage tolerance of composite aircraft
Flight testing results of T-2 CCV p 528 A88-40529	following failures for single-pilot rotorcraft	structures p 544 A88-38187
Structure and equipments of the T-2 CCV aircraft	[NASA-TM-100078] p 529 N88-22905	CREEP RUPTURE STRENGTH
p 514 A88-40530	CONTROLLERS	Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations
Determination of the aerodynamic characteristics of the	Multivariable control law design for the AFTI/F-16 with	p 541 A88-40174
Mission Adaptive Wing	a failed control surface using a parameter-adaptive	CRITICAL POINT
[AIAA PAPER 88-2556] p 489 A88-40733	controller - 530 N88 33040	Analytical study of friction and heat transfer in the vicinity
CONTROL EQUIPMENT	[AD-A189848] p 529 N88-22040	of a three-dimensional critical point at low and moderate
The PC/AT compatible computer as a mission control	CONVECTIVE HEAT TRANSFER Aerodynamic investigation by infrared imaging	Reynolds numbers p 483 A88-38847
center display processor at Ames-Dryden Flight Research	[AIAA PAPER 88-2523] p 545 A88-40713	CROSS FLOW
Facility [AIAA PAPER 88-2168] p 536 A88-38745	Heat transfer modeling of jet vane Thrust Vector Control	Experimental investigation of a jet impinging on a ground
CONTROL SIMULATION	(TVC) systems	plane in the presence of a cross flow
Multiple model parameter adaptive control for in-flight	[AD-A190106] p 524 N88-22034	[SAE PAPER 872326] p 478 A88-37195
simulation	CONVERGENCE	Numerical simulation of a subsonic jet in a crossflow [SAF PAPER 872343] p 478 A88-37209
[AD-A190568] p 537 N88-22044	Accuracy versus convergence rates for a three	SAE PAPER 872343 p 478 A88-37209  Numerical investigation of a jet in ground effect with a
CONTROL STABILITY	dimensional multistage Euler code INASA-CR-181665   p 554 N88-23519	crossflow
Stability and control augmentation system of 'ASKA'		[SAE PAPER 872344] p 478 A88-37210
[SAE PAPER 872334] p 527 A88-37203	CONVERGENT-DIVERGENT NOZZLES  Application of Navier-Stokes analysis to predict the	Measurements of turbulent flow behind a wing-body
Stability flight test verification by modal separation	internal performance of thrust vectoring two-dimensional	junction p 484 A88-38987
[AIAA PAPER 88-2129] p 512 A88-38729 Servo-actuator control for sampled-data feedback	convergent-divergent nozzles	The turbulence characteristics of a single impinging jet
disturbance rejection helicopters	[AIAA PAPER 88-2586] p 493 A88-40755	through a crossflow p 545 A88-39012
[ESA-TT-1002] p 529 N88-22903	COOLING	The effect of cross flow angle on the drag and lift
CONTROL SURFACES	Structural analyses of engine wall cooling concepts and	coefficients of non-circular cylinder with strakes [AIAA PAPER 88-2599] p 493 A88-40761
Multivariable control law design for the AFTI/F-16 with	materials p 542 N88-22405	[AIAA PAPER 88-2599] p 493 A88-40761 Comparison of different kinds of compact crossflow heat
a failed control surface using a parameter-adaptive	CORE FLOW	exchangers
controller	Theoretical model and numerical solution for	[ESA-TT-1076] p 550 N88-23169
[AD-A189848] p 529 N88-22040	compressible viscous vortex cores p 498 N88-22243	CRUDE OIL
Stability and control methodology for conceptual aircraft	CORNER FLOW  Laser velocimeter measurements in a wing-fuselage type	Turbine fuels from tar sands bitumen and heavy oil.
design. Volume 1: Methodology manual (AD-A1913141) p 530 N88-22906	juncture	Volume 2, phase 3: Process design specifications for a
[AD-A191314] p 530 N88-22906 CONTROL SYSTEMS DESIGN	[NASA-TM-100588] p 497 N88-22012	turbine fuel refinery charging San Ardo heavy crude oil
Microprocessor control of high-speed wind tunnel	CORROSION PREVENTION	(AD-A190120) p 543 N88-23011
stagnation pressure	Kryptonite they are not anticorrosive coatings for jet	CRUISING FLIGHT
[AIAA PAPER 88-2062] p 535 A88-37949	engine superallovs p 540 A88-37429	The initial calculation of range and mission fuel during
Development of a control system for an injector powered	Development of a high-temperature resistant (700 F),	conceptual design aircraft design [1 R-525] p 517 N88-22889
transonic wind tunnel	corrosion-preventive organic coating	[LR-525] p 517 N88-22889 CRYOGENIC WIND TUNNELS
[AIAA PAPER 88-2063] p 535 A88-37950	[AD-A191407] p 543 N88-23009	Highlights of experience with a flexible walled test
A study of digital fly-by-wire control system design for	CORROSION RESISTANCE	section in the NASA Langley 0.3-meter transonic cryogenic
elastic aircraft p 527 A88-38191	Corrosion-resistant thermal barrier coatings p 540 A88-38315	tunnel
Performance improvements of an F-15 airplane with an	COST ANALYSIS	[AIAA PAPER 88-2036] p 533 A88-37938
integrated engine-flight control system [AIAA PAPER 88-2175] p 527 A88-38747	A plan for coupling wind tunnel testing with CFD	Two-dimensional and three-dimensional adaptation at
[AIAA PAPER 88-2175] p 527 A88-38747 Control of an aircraft electric fuel pump drive	techniques	the T2 transonic wind tunnel of Onera/Cert
p 524 A88-39133	[AIAA PAPER 88-1996] p 531 A88-37909	[AIAA PAPER 88-2038] p 534 A88-37940
Status and trend in CCV p 528 A88-40526	COST EFFECTIVENESS	Heating requirements and nonadiabatic surface effects
Development overview of the T-2 CCV	New structural technologies for the Dornier 328	for a model in the NTF cryogenic wind tunnel [AIAA PAPER 88-2044] p 534 A88-37944
p 528 A88-40527	fuselage p 473 A88-37297	
FBW system and control law of the T-2 CCV	COUNTER ROTATION	CURVE FITTING  Using frequency-domain methods to identify XV-15
p 528 A88-40528	Scale model acoustic testing of counterrotating fans	aeroelastic modes
Decentralized approach to the design of automatic flight	[AIAA PAPER 88-2057] p 523 A88-37947	[SAE PAPER 872385] p 510 A88-37234
control systems p 528 A88-40858	Porous wind tunnel corrections for counterrotation	CURVED PANELS
Linear state space modeling of a turbofan engine	propeller testing [NASA-TM-100873] p 498 N88-22019	A study of damage tolerance in curved composite
[AD-A190110] p 524 N88-22035	[NASA-TM-100873] p 498 N88-22019 The 2-D and 3-D time marching transonic potential flow	panels
Design of an integrated control system for flutter margin	method for propfans p 501 N88-23245	[AD-A190617] p 541 N88-22092
augmentation and gust load alleviation, tested on a	CRACK ARREST	CYCLIC LOADS
dynamic windtunnel model	Life of gas turbine engine disks with cracks	High-temperature combustor liner tests in structural
[PB88-149885] p 528 N88-22038	p 544 A88-37549	component response test facility p 525 N88-22383
Application of eigenstructure assignment techniques in	CRACK GEOMETRY	Life assessment of combustor liner using unified
the design of a longitudinal flight control system	Some aspects of the reliability analysis of aircraft	constitutive models p 525 N88-22384
[AD-A189644] p 528 N88-22039	structures p 544 A88-38181	Development of a flexible and economic helicopter
Development of a mobile research flight test support	CRACK INITIATION	engine monitoring system [PB88-165147] p 517 N88-22887
capability	Life prediction modeling based on cyclic damage	CYLINDERS
[NASA-TM-100428] p 506 N88-22883	accumulation p 548 N88-22426	An experimental investigation of the aerodynamic
Basic design of a flight director system for NAL STOL	Fatigue damage modeling for coated single crystal superalloys p 542 N88-22427	characteristics of slanted base ogive cylinders using
research aircraft (DE88-751806) p 521 N88-22897	superalloys p 542 N88-22427 CRACK PROPAGATION	magnetic suspension technology
	CHACK FROM AGAINM	
	Improving the reliability of silicon nitride - A case study	
Analysis and design of gain scheduled control systems	Improving the reliability of silicon nitride - A case study p 540 A88-38316	Mechanisms of active control for noise inside a vibrating cylinder p 555 A88-39722

Mode 2 fracture mechanics

p 548 N88-22418

An investigation of the ability to recover from transients

p 529 N88-22905

following failures for single-pilot rotorcraft [NASA-TM-100078] p 52

systems [NASA-CR-182867]

p 529 N88-22904

Investigation of combustion in large vortices [AD-A190406] p 541

using a three component laser velocimeter

Properties of a half-delta wing vortex

Comparison of Euler and Navier-Stokes solutions for

Applications of an Euler aerodynamic method to

Wing vortex-flows up into vortex breakdown - A

p 483 A88-38985

p 485 A88-39278

p 487 A88-40708

p 487 A88-40709

[AIAA PAPER 88-2024]

vortex flow over a delta wing

free-vortex flow simulation

[AIAA PAPER 88-2517]

[AIAA PAPER 88-2518]

numerical simulation

SUBJECT INDEX	
CVI INDRICAL DODIES	
CYLINDRICAL BODIES  The effect of cross flow angle	on the drag and lift
coefficients of non-circular cylinder v	with strakes
[AIAA PAPER 88-2599] A study of damage tolerance in	p 493 A88-40761
panels	curved composite
[AD-A190617]	p 541 N88-22092
D	
DAMAGE	
A study of damage tolerance panels	in curved composite
[AD-A190617]	p 541 N88-22092
DAMAGE ASSESSMENT  Life prediction modeling based	on avalia damaga
accumulation	p 548 N88-22426
Towards a damage tolerance philo	
materials and structures [NASA-TM-100548]	p 542 N88-22949
DATA BASES	•
Airborne data bases - A quiet revo	
A description of an automated d	
program [NASA-TM-100609]	p 554 N88-23463
DATA COMPRESSION	p 554 1400-25465
Flight test imagery - Getting more	
[AIAA PAPER 88-2102] DATA LINKS	p 505 A88-38714
Joint Tactical Information Distribut	tion System (JTIDS)
class 2 terminal flight test [AIAA PAPER 88-2119]	- FOE ADD 00700
DATA PROCESSING	p 505 A88-38720
Real-time flight test data distributio	
[NASA-TM-100424] Digital processing of flight data of	p 538 N88-22050 a helicopter without
using anti-aliasing filters	a nonceptor introdu
[ESA-TT-1094] DATA PROCESSING EQUIPMENT	p 517 N88-22890
An airborne realtime data process	sing and monitoring
system for research aircraft	_
[AIAA PAPER 88-2165] DATA SAMPLING	p 506 A88-38743
Digital processing of flight data of	a helicopter without
using anti-aliasing filters [ESA-TT-1094]	p 517 N88-22890
Servo-actuator control for sample	
disturbance rejection helicopters	
[ESA-TT-1002] DATA STORAGE	p 529 N88-22903
Method and device for the detection	on and identification
of a helicopter [NASA-TT-20251]	p 556 N88-22698
DATA TRANSMISSION	p 556 1466-22696
Development of fiber optic data but	
DE HAVILLAND AIRCRAFT	p 555 A88-38344
A review of the de Havilland augment	tor-wing powered-lift
concept and its future applications [SAE PAPER 872313]	p 507 A88-37184
DECELERATION	p 507 A66-37164
Soft-ground aircraft arresting system [AD-A190838]	
DEFECTS	p 539 N88-22912
The use of rule induction to assist	in the diagnosis of
avionic circuit board defects [ETN-88-92077]	p 521 N88-22899
Nondestructive evaluation of larg	ge scale composite
components	
[AD-A190998]	p 542 N88-22954

Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174 p 541 N88-22121 Turbulent friction on a delta wing p 480 A88-37657 Measurement of leading edge vortices from a delta wing p 544 A88-37929 Visualization and wake surveys of vortical flow over a p 482 A88-38377

DIGITAL NAVIGATION

Navier Stokes computation of the flow field over delta wings with spanwise leading edge blowing [AIAA PAPER 88-2558] p 489 A88-40734 Leading edge vortex dynamics on a pitching delta [AIĂA PAPER 88-2559] p 489 A88-40735 Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPÉR 88-2563] p 490 A88-40737 Experimental measurements on an oscillating 70-degree elta wing in subsonic flow (AIAA PAPER 88-2576) p 491 A88-40745 Nonintrusive measurements of vortex flows on delta vings in a water tunnel [AIAA PAPER 88-2595] p 493 A88-40760 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of the transonic flow at the eward side of a delta wing at high incidence ILR-5181 p 499 N88-22861 Investigation on the movement of vortex burst position rith dynamically changing angle of attack for a schematic deltawing in a watertunnel with correlation to similar studies in windtunnel p 550 N88-23152 DEPOSITION Standardized ice accretion thickness as a function of cloud physics parameters ESA-TT-1080] **DESIGN ANALYSIS** Calculation of external-internal flow fields for mixed-compression inlets Optimizing advanced propeller designs by simultaneously updating flow variables and design [AIAA PAPER 88-2532] Improvements to tilt rotor performance through passive [NASA-TM-100583] Expanded envelope concepts

[SPIE-778] p 553 N88-23346 p 479 A88-37353 p 488 A88-40718

p 548 N88-22434 Water facilities in retrospect and prospect: An uminating tool for vehicle design p 539 N88-23126 illuminating tool for vehicle design DETECTION aircraft for

control-element failure detection and identification p 507 N88-22886 [NASA-CR-181664] DIFFERENCE EQUATIONS

Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 DIFFRACTION

Ultrasonic Time-Of-Flight Diffraction (TOFD) measurements of crack depths in an acceleration reservoir of a high velocity research gun [DE88-006644] p 538 N88-22907

DIFFUSERS The calculation of the flow through a two-dimensional faired diffuser p 485 A88-39030 DIGITAL DATA

A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393 **DIGITAL ELECTRONICS** 

Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901 DIGITAL FILTERS

Digital processing of flight data of a helicopter without using anti-aliasing filters [ESA-TT-1094] p 517 N88-22890

Current trend of digital map processing p 506 A88-40533 DIGITAL SIMULATION Adaptation of flexible wind tunnel walls for supersonic

[AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China

[AIAA PAPER 88-2040] p 534 A88-37942 Linear dynamics of supersonic inlet p 482 A88-38186

by viscous flow p 482 A88-38343 Flow analysis around aircraft computation Simulation in support of flight test - In retrospect [AIAA PAPER 88-2130] p 512 A88-38730 DIGITAL SYSTEMS

A study of digital fly-by-wire control system design for elastic aircraft p 527 A88-38191 Preliminary airworthiness evaluation of the UH-60A with

Advanced Digital Optical Control System (ADOCS) [AD-A190674] p 516 N88-22030 Subharmonic aliasing and its effects on the AFTI/F-16

digital flight control system (AD-A1906141 p 529 N88-22042 DIGITAL TECHNIQUES

Digital avionics design and reliability analyzer (NASA-CR-181641) p 554 N88-23472 **DIRECTION FINDING** 

Taxiway safety using mode S SSR

p 519 A88-39495

**DISPENSERS** Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing system

IAD-A1906041 p 516 N88-22029 **DISPLAY DEVICES** 

Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft (SAE PAPER 872316)

The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research

I AIAA PAPER 88-2168 | p 536 A88-38745 Navigation and performance computer

p 519 A88-40518

Trends and problems of head-up display

p 519 A88-40534 Flat panel display trends p 545 A88-40535 Avionics for transport aircraft - Current development p 520 A88-41098

Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987

p 520 A88-41361 Suppressing display cockpit reflections

p 515 A88-41364

Effects of update and refresh rates on flight simulation visual displays

[NASA-TM-100415] p 516 N88-22033 Geometric modeling of flight information for graphical

IAD-A1904841 p 537 N88-22043 Real-time flight test data distribution and display [NASA-TM-100424] p 538 N88-22050

Basic design studies for the realization of liquid crystal display systems in aircraft

IVA-87-0011 p 521 N88-22900

DISTRIBUTED PROCESSING

Decentralized approach to the design of automatic flight control systems p 528 A88-40858

DITCHING (LANDING)

An analytical method for the ditching analysis of an

airborne vehicle [AIAA PAPER 88-2521] p 514 A88-40711 DOPPLER NAVIGATION

A fully integrated GPS/Doppler/inertial navigation system p 504 A88-37400 DORNIER AIRCRAFT

New structural technologies for the Dornier 328 fuselage p 473 A88-37297 Large-scale model for experimental wind tunnel investigations p 531 A88-37298 Dornier 328 taking shape

p 514 A88-39415 DRAG MEASUREMENT Drag measurements on a body of revolution in Langley's 3-inch Magnetic Suspension and Balance System

AIAA PAPER 88-2010] p 532 A88-37918 DRAG REDUCTION

Experimental investigation of non-planar sheared outboard wing planforms

[AIAA PAPER 88-2549] p 489 A88-40731 The effect of cross flow angle on the drag and lift coefficients of non-circular cylinder with strakes [AIAA PAPER 88-2599] p 493 A88-40761

Flight tests of external modifications used to reduce blunt base drag [AIAA PAPER 88-2553] p 494 A88-40763

Riblet drag reduction at flight conditions [AIAA PAPER 88-2554] p 494 A88-40764 Control of laminar flow around of the wing in free-air

conditions IAD-A1874791 p 495 N88-22004

Special report on Bell ACAP full-scale aircraft crash

SAE PAPER 872362] p 509 A88-37223 **DUCTED FLOW** Flow in out-of-plane double S-bends

p 484 A88-39011 DUCTS

Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct

[AD-A190772] p 547 N88-22320 DURABILITY

Computational structural mechanics for engine structures p 525 N88-22399

DYNAMIC CHARACTERISTICS The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023

KRASH parametric sensitivity study: Transport category	ELECTRIC FIELDS	ENGINE TESTS  Test stand performance of a convertible engine for
airplanes	Experimental comparison of lightning simulation	advanced V/STOL and rotorcraft propulsion
[AD-A189962] p 515 N88-22024	techniques to CV-580 airborne lightning strike	[SAE PAPER 872355] p 523 A88-37217
DYNAMIC CONTROL	measurements [AD-A190576] p 552 N88-22496	Small engine components test facility turbine testing
Linear state space modeling of a turbofan engine	ELECTRIC MOTORS	cell
[AD-A190110] p 524 N88-22035	Control of an aircraft electric fuel pump drive	[NASA-TM-100887] p 525 N88-22037
Problems in nonlinear continuum dynamics	p 524 A88-39133	High-temperature combustor liner tests in structural
[AB-A130350]	ELECTRIC POWER SUPPLIES	component response test facility p 525 N88-22383
DYNAMIC LOADS  Pressure measurements of impinging jet with asymmetric	The use of a computer model to investigate design	ENVIRONMENTAL TESTS
nozzle	compatibility between the QF-4 aircraft and the	Development of fiber optic data bus for aircraft p 555 A88-38344
[NASA-CR-182759] p 497 N88-22011	AQM-127A LAIAA PAPER 88-21431 p 512 A88-38736	·
DYNAMIC MODELS	[AIAA PAPER 88-2143] p 512 A88-38736 ELECTRICAL MEASUREMENT	EQUATIONS OF MOTION A numerical model of unsteady, subsonic aeroelastic
Review of transition effects on the problem of dynamic	Measurement of multipath propagation of	behavior
simulation of wind tunnel tests	electromagnetic waves in actual airport environments	[NASA-TM-101126] p 499 N88-22862
[AIAA PAPER 88-2004] p 532 A88-37915	p 506 A88-39813	Application of Navier-Stokes analysis to stall flutter
Use of dynamically scaled models for studies of the	ELECTROMAGNETIC PULSES	p 530 N88-23249
high-angle-of-attack behavior of airplanes	EMR (Electromagnetic Radiation) test facilities	EQUIPMENT SPECIFICATIONS
p 535 A88-38692	evaluation of reverberating chamber located at RADC	Diagnostic design requirements for integrated avionic
DYNAMIC RESPONSE	(Rome Air Development Center), Griffiss AFB (Air Force	subsystems
Linear dynamics of supersonic inlet	Base), Rome, New York [PB88-178827] p 538 N88-22048	[AIAA PAPER 88-2171] p 553 A88-38746
Shape sensitivity analysis of wing static aeroelastic	Investigations of test methodology for the stress loading	Research sensors p 548 N88-22430
characteristics	facility	ERROR ANALYSIS
[NASA-TP-2808] p 516 N88-22031	[PB88-166095] p 538 N88-22049	Aircraft accident report: North Star Aviation, Inc., PA-32
Influence of unsteady aerodynamic forces on dynamic	ELECTROMAGNETIC RADIATION	RT-300, N39614 and Alameda Aero Club Cessna 172,
response of variable sweep aircraft p 516 N88-22245	Measurement of multipath propagation of	N75584, Oakland, California, March 31, 1987
Investigation on the movement of vortex burst position	electromagnetic waves in actual airport environments p 506 A88-39813	[PB87-910412] p 502 N88-22021
with dynamically changing angle of attack for a schematic	·	ERROR DETECTION CODES
deltawing in a watertunnel with correlation to similar studies	ELECTROMAGNETISM  Progress towards extreme attitude testing with Magnetic	GPS integrity monitoring for commercial applications
in windtunnel p 550 N88-23152	Suspension and Balance Systems	using an IRS as a reference p 505 A88-37412
Stall flutter analysis of propfans p 552 N88-23256	[AIAA PAPER 88-2012] p 532 A88-37920	ESTIMATES
DYNAMIC STABILITY	ELECTRON MICROSCOPY	Analysis of a range estimator which uses MLS angle
An experimental study to determine the flow and the	The role of electron microscopy in gas turbine materials	measurements INASA-CR-1828961 p 507 N88-22884
subsonic static and dynamic stability characteristics of aircraft operating at high angles-of-attack	development p 545 A88-40327	(1111011011101111
p 518 N88-23129	ELECTRONIC EQUIPMENT Investigations of test methodology for the stress loading	EULER EQUATIONS OF MOTION
DYNAMIC STRUCTURAL ANALYSIS		Flow solution on a dual-block grid around an airplane p 479 A88-37355
Lewis Structures Technology, 1988. Volume 2: Structural	facility [PB88-166095] p 538 N88-22049	·
Mechanics	Nondestructive evaluation of large scale composite	Comparison of Euler and Navier-Stokes solutions for vortex flow over a delta wing p 485 A88-39278
[NASA-CP-3003-VOL-2] p 548 N88-22382	components	Applications of an Euler aerodynamic method to
Structural dynamics branch research and	[AD-A190998] p 542 N88-22954	free-vortex flow simulation
accomplishments for fiscal year 1987	ELECTRONIC FILTERS	[AIAA PAPER 88-2517] p 487 A88-40708
[NASA-TM-100279] p 549 N88-22446	Advanced capacitor development [AD-A189985] p 546 N88-22276	Transonic Euler calculations of a wing-body
Lewis Structures Technology, 1988. Volume 1: Structural	[AD-A189985] p 546 N88-222/6 EMBEDDED COMPUTER SYSTEMS	configuration using a high-accuracy TVD scheme
Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226	A digital P-code GPS reciever and its applications to	[AIAA PAPER 88-2547] p 488 A88-40729
INASA-CP-3003-VOL-11 P 331 1400 20220		Three-dimensional unsteady transonic viscous-inviscid
·	embedded systems p 503 A66-37393	
DVNAMIC TESTS	FNERGY CONSERVATION	interaction using the Euler and boundary-layer equations
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS	ENERGY CONSERVATION  NASA advanced turboprop research and concept	interaction using the Euler and boundary-layer equations
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  FNGINE AIRFRAME INTEGRATION	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385  KRASH parametric sensitivity study: Transport category	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  FNGINE AIRFRAME INTEGRATION	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler
PYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes  [AD-A189962] p 515 N88-22024	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2
PYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes  [AD-A189962] p 515 N88-22024	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three
PYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519
PYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  FUROPEAN AIRBUS
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems
DYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS  Activities report of Lufthansa [ISSN-0176-5086]  EDDY VISCOSITY  Turbulent eddy viscosity modeling in transonic	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing  [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history  [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design  [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history  [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design  [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMB (Electromagnetic Radiation) test facilities
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC
Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS  Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  EIGENVALUES  Application of eigenstructure assignment techniques in	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York
Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS  Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  EIGENVALUES  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A1907721] p 547 N88-22320	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772]  ENGINE MONITORING INSTRUMENTS	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048
Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS  Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  EIGENVALUES  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772]  ENGINE MONITORING INSTRUMENTS	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system NOISE	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system  EVENCINE TO STATE OF THE PROPER OF THE PROPERTY ASSOCIATION OF THE PROPERTY OF THE P	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 524 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] P 528 N88-22039 Reduced order models for nonlinear aerodynamics	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248 Reduced order models for nonlinear aerodynamics p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 528 N88-22039 Reduced order models for nonlinear aerodynamics	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872347] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-23248 EJECTORS	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PBB8-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 508 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 508 N88-23248 EIGENVECTORS Application of eigenstructure assignment aerodynamics p 501 N88-23248	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] P 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] P 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] P 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EJECTORS Advances in ejector thrust augmentation [SAE PAPER 872322] P 522 A88-37191 Development of lift ejectors for STOVL combat aircraft	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft — Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European — low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual — vibration, structural life, and engine diagnostics system  P 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-4080	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert system
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086]  p 476 N88-22855 EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592]  p 493 A88-40758 EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644]  p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248 EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248 EJECTORS Advances in ejector thrust augmentation [SAE PAPER 872324] Development of lift ejectors for STOVL combat aircraft (SAE PAPER 8723241)  p 522 A88-37193	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A199966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280  Small engine components test facility turbine testing	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 555 A88-38705
PYNAMIC TESTS  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385  KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS  Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  EIGENVALUES  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039  Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039  Reduced order models for nonlinear aerodynamics p 501 N88-23248  EJECTORS  Advances in ejector thrust augmentation [SAE PAPER 872324] p 522 A88-37191  Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193  The synthesis of ejector lift/vectored thrust for STOVL	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280  Small engine components test facility turbine testing cell	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert system  [AIAA PAPER 88-2082] p 505 A88-3805  Kalman filter residual expert system
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program  (NASA-TM-100891) p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280  Small engine components test facility turbine testing cell  [NASA-TM-100887] p 555 N88-22037	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  Kalman filter residual expert system [AIAA PAPER 88-2082] p 529 N88-22041
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] P 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] P 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] P 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EJECTORS Advances in ejector thrust augmentation [SAE PAPER 872322] Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] P 522 A88-37193 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872378] Numerical and experimental investigation of multiple	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - in the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280  Small engine components test facility turbine testing cell  [NASA-TM-100887] p 525 N88-22037  Specialty three-dimensional finite element analysis codes	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762 On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872312] p 522 A88-37191 Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-02612] p 538 N88-22046  EXPERT SYSTEMS Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 Kalman filter residual expert system [AIAA PAPER 88-2082] p 529 N88-22041 Rapid prototyping of complex avionics system
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962] p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] p 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Advances in ejector thrust augmentation [SAE PAPER 872322] Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] Development of lift ejector strovy Locubat aircraft [SAE PAPER 872324] The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872378] Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280  Small engine components test facility turbine testing cell [NASA-TM-100887] p 525 N88-22037  Specialty three-dimensional finite element analysis codes  Computational structural mechanics for engine	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 529 N88-22041  Rapid prototyping of complex avionics system architectures
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] P 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] P 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] P 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EJECTORS Advances in ejector thrust augmentation [SAE PAPER 872322] Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] P 522 A88-37193 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872378] Numerical and experimental investigation of multiple	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 548 N88-22397  Specialty three-dimensional finite element analysis codes p 548 N88-22393  Computational structural mechanics for engine structures p 525 N88-22399	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  Kalman filter residual expert system [AIAA PAPER 88-2082] p 529 N88-22041  Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086] P 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644] p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Advances in ejector thrust augmentation [SAE PAPER 872322] Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872378] Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] P 547 N88-2320  ELASTIC CYLINDERS	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-39276  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280  Small engine components test facility turbine testing cell  [NASA-TM-100887] p 525 N88-22393  Computational structural mechanics for engine structures p 525 N88-22393  Evaluation of ceramic thermal barrier coatings for gas	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762 On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182 Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 Kalman filter residual expert system [AIAA PAPER 88-2082] p 529 N88-22041 Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898 The use of rule induction to assist in the diagnosis of
PYNAMIC TESTS Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385 KRASH parametric sensitivity study: Transport category airplanes [AD-A189962]  p 515 N88-22024   E  ECONOMIC FACTORS Activities report of Lufthansa [ISSN-0176-5086]  p 476 N88-22855  EDDY VISCOSITY Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592]  p 493 A88-40758  EIGENVALUES Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644]  p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EIGENVECTORS Application of eigenstructure assignment techniques in the design of a longitudinal flight control system [AD-A189644]  p 528 N88-22039 Reduced order models for nonlinear aerodynamics p 501 N88-23248  EJECTORS Advances in ejector thrust augmentation [SAE PAPER 872322]  Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324]  Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324]  Development of lift ejector lift/vectored thrust for STOVL [SAE PAPER 872324]  p 522 A88-37193  The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872378]  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772]  p 547 N88-2230	ENERGY CONSERVATION  NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  ENGINE AIRFRAME INTEGRATION  Propulsion/aerodynamic integration in ASTOVL combat aircraft Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202  ENGINE DESIGN  Lift engines - Applied history [SAE PAPER 872347] p 522 A88-37213  STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214  Cool European low-temperature helicopter engine p 524 A88-39276  Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  ENGINE INLETS  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  ENGINE MONITORING INSTRUMENTS  Osprey's VSLED - Rewriting the maintenance manual vibration, structural life, and engine diagnostics system p 474 A88-39325  ENGINE NOISE  Turbofan engine core noise source diagnostics p 524 A88-39707  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-22702  ENGINE PARTS  Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 548 N88-22397  Specialty three-dimensional finite element analysis codes p 548 N88-22393  Computational structural mechanics for engine structures p 525 N88-22399	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747  Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762  On the prediction of highly vortical flows using an Euler equation model, part 2 [AD-A190245] p 547 N88-22305  Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519  EUROPEAN AIRBUS  Aerospace equipment - Evolution and future problems p 474 A88-40522  EVALUATION  EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York [PB88-178827] p 538 N88-22048  EXHAUST GASES  Landing surface characteristics unique to V/STOL aircraft [SAE PAPER 872310] p 530 A88-37182  Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191  Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046  EXPERT SYSTEMS  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  Kalman filter residual expert system [AIAA PAPER 88-2082] p 529 N88-22041  Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898

F-111 AIRCRAFT
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AFTI/F-111 Mission Adaptive Wing flight research IAIAA PAPER 88-21181 p 511 A88-38719

Determination of the aerodynamic characteristics of the Mission Adaptive Wing

[AIAA PAPER 88-2556] p 489 A88-40733

#### F-14 AIRCRAFT

Techniques used in the F-14 variable-sweep transition flight experiment

[AJAA PAPER 88-2110] p 513 A88-38762

#### F-15 AIRCRAFT

The F-15 STOL and maneuver technology demonstrator (S/MTD) program

[SAE PAPER 872383] p 510 A88-37232 F-15E flight test program overview - March 1988

[AIAA PAPER 88-2077] p 511 A88-38704 Performance improvements of an F-15 airplane with an integrated engine-flight control system

p 527 A88-38747 [AIAA PAPER 88-2175]

#### F-16 AIRCRAFT

The numerical simulation of the Navier-Stokes equations for an F-16 configuration

[AIAA PAPER 88-2507] p 487 A88-40702 Analytical evaluation of birdstrike against a F-16A

laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868 Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive

controller [AD-A189848] p 529 N88-22040 Subharmonic aliasing and its effects on the AFTI/F-16

digital flight control system IAD-A190614] p 529 N88-22042

#### F-4 AIRCRAFT

The use of a computer model to investigate design compatibility between the QF-4 aircraft and the AQM-127A

[AIAA PAPER 88-2143] p 512 A88-38736

#### FAIL-SAFE SYSTEMS

Towards a damage tolerance philosophy for composite materials and structures

p 542 N88-22949 [NASA-TM-100548]

#### FAILURE

Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive controller

[AD-A189848] p 529 N88-22040

#### **FAILURE ANALYSIS**

Some aspects of the reliability analysis of aircraft p 544 A88-38181 Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit

[AIAA PAPER 88-2172] p 553 A88-38765 The use of rule induction to assist in the diagnosis of avionic circuit board defects

p 521 N88-22899 IETN-88-920771 An investigation of the ability to recover from transients

following failures for single-pilot rotorcraft [NASA-TM-100078] p 5 p 529 N88-22905

#### **FAILURE MODES**

p 548 N88-22418 Mode 2 fracture mechanics

#### FAN BLADES Scale model acoustic testing of counterrotating fans

p 523 A88-37947 1AIAA PAPER 88-20571 The composite blade structural analyzer (COBSTRAN) p 525 N88-22390

#### **FATIGUE (MATERIALS)**

Lewis Structures Technology, 1988. Volume 2: Structural Mechanics

[NASA-CP-3003-VOL-2] n 548 N88-22382 Mode 2 fracture mechanics p 548 N88-22418 **FATIGUE LIFE** 

Life of gas turbine engine disks with cracks

p 544 A88-37549 Life assessment of combustor liner using unified p 525 N88-22384 constitutive models Computational structural mechanics for engine p 525 N88-22399 Computerized life and reliability modelling for turboprop transmissions

[NASA-TM-100918] p 551 N88-23220

#### **FATIGUE TESTS**

Flight fatigue testing of helicopters --- Russian book p 510 A88-37703 Effect of load duration on the fatigue behaviour of

graphite/epoxy laminates containing delaminations p 541 A88-40174

#### FEEDBACK CONTROL

A review of Magnetic Suspension and Balance [AIAA PAPER 88-2008] p 532 A88-37917

Development of a control system for an injector powered transonic wind tunnel

[AIAA PAPER 88-2063] p 535 A88-37950 Control of an aircraft electric fuel pump drive

p 524 A88-39133 Application of eigenstructure assignment techniques in the design of a longitudinal flight control system

IAD-A1896441 p 528 N88-22039 Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive controller

[AD-A189848] p 529 N88-22040 Servo-actuator control for sampled-data feedback

disturbance rejection --- helicopters p 529 N88-22903 [ESA-TT-1002] Analysis and design of gain scheduled control systems

NASA-CR-182867) FIBER COMPOSITES

p 529 N88-22904 The composite blade structural analyzer (COBSTRAN)

p 525 N88-22390 Design studies of primary aircraft structures in ARALL laminates

p 517 N88-22888 A study of failure characteristics in thermoplastic

composite material AD-A190613] p 542 N88-22940

#### FIBER OPTICS

A role for fibre optics in antenna measurements p 544 A88-38116

Development of fiber optic data bus for aircraft p 555 A88-38344

#### FIELD OF VIEW

Developing a wide field of view HMD for simulators -Helmet Mounted Display p 520 A88-4136 p 520 A88-41367 An integrated approach to helmet display system design p 520 A88-41368

#### FIGHTER AIRCRAFT

Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 Flight propulsion control integration for V/STOL aircraft

[SAE PAPER 872330] p 522 A88-37199 Propulsion/aerodynamic integration in ASTOVL combat aircraft --- Advanced Short Take-Off Vertical Landing [SAE PAPER 872333] p 508 A88-37202 NASA supersonic STOVL propulsion technology

[SAE PAPER 872352] p 523 A88-37215 The synthesis of ejector lift/vectored thrust for STOVL

p 523 A88-37228 [SAE PAPER 872378] Configuration E-7 supersonic STOVL fighter/attack technology program

p 509 A88-37229 [SAE PAPER 872379] SAE PAPER 8/23/9]
A supersonic design with V/STOL capability
SAF PAPER 8/2382] p 509 A88-3/231 SAE PAPER 872382]

Wave drag and high-speed performance of supersonic STOVL fighter configurations

(SAE PAPER 872311) p 479 A88-37235 Development of an integrated set of research facilities for the support of research flight test

[AIAA PAPER 88-2096] p 535 A88-38712 Program review of European Fighter Aircraft
[AIAA PAPER 88-2120] p 511 A88-38721

Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model

[AIAA PAPER 88-2134] p 512 A88-38731 Further analysis of wing rock generated by forebody vortices [AIAA PAPER 88-2597]

p 494 A88-40768 X-31 - Through the grape barrier --- highly maneuverable fighter aircraft p 515 A88-41250 Model selection for the multiple model adaptive algorithm for in-flight simulation

[AD-A189715] p 515 N88-22022 Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive

[AD-A189848] p 529 N88-22040 Kalman filter residual expert system

[AD-A190520] p 529 N88-22041 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack

#### p 549 N88-23130 FINITE DIFFERENCE THEORY

Application of efficient iteration scheme AF2 to computations of transonic full-potential flows over

wing-body combinations p 481 A88-38177 Fourth-order accurate calculations of the 3-D compressible boundary layers on aerospace configurations

[AIAA PAPER 88-2522] p 487 A88-40712 Numerical analysis of multiple element high lift devices by Navier Stokes equation using implicit TVD finite volume

[AIAA PAPER 88-2574] p 491 A88-40743 Reduced order models for nonlinear aerodynamics p 501 N88-23248

#### FINITE ELEMENT METHOD

Numerical calculations of the natural vibrations of turbomachine blades using the finite element method

p 523 A88-37543 A study of aeroelastic stability for the model support system of the National Transonic Facility

p 533 A88-37936 [AIAA PAPER 88-2033] Computation of cascade flow using a finite-flux-element method p 485 A88-39488

Analytical evaluation of birdstrike against a F-16A laminated canopy

p 514 A88-40868 [AIAA PAPER 88-2268] On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269

Specialty three-dimensional finite element analysis p 548 N88-22393 MHOST: An efficient finite element program for inelastic

p 525 N88-22394 analysis of solids and structures Fatigue damage modeling for coated single crystal p 542 N88-22427 superallovs

#### FINITE VOLUME METHOD

Flow solution on a dual-block grid around an airplane p 479 A88-37355 Numerical analysis of multiple element high lift devices

by Navier Stokes equation using implicit TVD finite volume method

[AIAA PAPER 88-2574] p 491 A88-40743 Mixed direct-inverse problem of transonic cascade

p 498 N88-22244 The 2-D and 3-D time marching transonic potential flow method for propfans p 501 N88-23245

FIRE CONTROL Method and device for the detection and identification

of a helicopter p 556 N88-22698

#### [NASA-TT-20251] **FIXED WINGS**

A flexible computer program for aircraft flight test performance

[AIAA PAPER 88-2125] p 553 A88-38725 An integrated approach to helmet display system p 520 A88-41368

#### FLAME SPECTROSCOPY

La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June (ESA-TT-1075) p 550 N88-23161

#### FLAPS (CONTROL SURFACES)

CFRP landing flaps for the Airbus A320

#### p 474 A88-39416 FLAT PLATES

Supersonic jet plume interaction with a flat plate

[SAE PAPER 872361] p 479 A88-37222 Measurements of turbulent flow behind a wing-body p 484 A88-38987

Experimental and numerical analysis of the formation and evolution of streamwise vortices in the plane wake behind a flat plate p 484 A88-39017 Flat panel display trends p 545 A88-40535

#### FLIGHT CHARACTERISTICS

The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711

Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481

Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Bifurcations in unsteady aerodynamics-implications for testing [NASA-TM-100083]

p 497 N88-22014 Airworthiness and flight characteristics test of a ski assembly for the UH-60A Black Hawk helicopter [AD-A191414] p 518 N88-22895

#### FLIGHT CONTROL

Flight evaluation of an integrated control and display system for high-precision manual landing flare of owered-lift STOL aircraft

ISAE PAPER 8723161 p 508 A88-37187 Integrated control and display research for transition and vertical flight on the NASA V/STOL Research Aircraft (VSRA)

[SAE PAPER 872329] p 526 A88-37198 Flight propulsion control integration for V/STOL aircraft

[SAE PAPER 872330] p 522 A88-37199 The VAAC VSTOL flight control research project ---Vectored thrust Aircraft Advanced flight Control

[SAE PAPER 872331] p 526 A88-37200 A highly monitored AV-8B Harrier II digital flight control system

[SAE PAPER 872332] p 527 A88-37201 Stability and control augmentation system of 'ASKA' [SAE PAPER 8723341 p 527 A88-37203

SUBJECT INDEX **FLIGHT ENVELOPES** 

	Preliminary airworthiness evaluation of the UH-60A	Flight test results of a vector-based failure detection
Performance improvements of an F-15 airplane with an integrated engine-flight control system	equipped with the XM-139 VOLCANO mine dispensing	and isolation algorithm for a redundant strapdown inertial
[AIAA PAPER 88-2175] p 527 A88-38747	system	measurement unit
FBW system and control law of the T-2 CCV	[AD-A190604] p 516 N88-22029	[AIAA PAPER 88-2172] p 553 A88-38765
p 528 A88-40528	FLIGHT TESTS  Performance flight testing of a single engine powered	Keys to a successful flight test [AIAA PAPER 88-2174] p 519 A88-38766
Avionics for transport aircraft - Current development status p 520 A88-41098	lift aircraft	Flight testing results of T-2 CCV p 528 A88-40529
Application of eigenstructure assignment techniques in	[SAE PAPER 872314] p 507 A88-37185	Flight tests of external modifications used to reduce blunt
the design of a longitudinal flight control system	Flight evaluation of an integrated control and display	base drag
[AD-A189644] p 528 N88-22039	system for high-precision manual landing flare of	[AIAA PAPER 88-2553] p 494 A88-40763
Multivariable control law design for the AFTI/F-16 with	powered-lift STOL aircraft	The effect of aircraft angular vibrations on the quality, of remotely sensed images p 520 A88-41096
a failed control surface using a parameter-adaptive	[SAE PAPER 872316] p 508 A88-37187	Bifurcations in unsteady aerodynamics-implications for
controller [AD-A189848] p 529 N88-22040	Some topics of ASKA's flight test results and its future	testing
Kalman filter residual expert system	plan  SAF PAPER 872317  p 508 A88-37188	[NASA-TM-100083] p 497 N88-22014
[AD-A190520] p 529 N88-22041	SAE PAPER 872317  p 508 A88-37188   T-33 aircraft demonstration of GPS aided inertial	Real-time flight test data distribution and display
Subharmonic aliasing and its effects on the AFTI/F-16	navigation p 504 A88-37403	[NASA-TM-100424] p 538 N88-22050
digital flight control system	Flight fatigue testing of helicopters Russian book	Development of a mobile research flight test support capability
[AD-A190614] p 529 N88-22042 Multiple model parameter adaptive control for in-flight	p 510 A88-37703	[NASA-TM-100428] p 506 N88-22883
simulation	Development of fiber optic data bus for aircraft	Digital processing of flight data of a helicopter without
[AD-A190568] p 537 N88-22044	p 555 A88-38344	using anti-aliasing filters
Basic design of a flight director system for NAL STOL	AIAA Flight Test Conference, 4th, San Diego, CA, May	[ESA-TT-1094] p 517 N88-22890
research aircraft	18-20, 1988, Technical Papers p 510 A88-38701	Airworthiness and flight characteristics test of a ski assembly for the UH-60A Black Hawk helicopter
[DE88-751806] p 521 N88-22897	Aircraft flight flutter testing at the NASA Ames-Dryden	[AD-A191414] p 518 N88-22895
Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901	Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702	Experimental investigation of Hover flowfields in water
Stability and control methodology for conceptual aircraft	Autoland testing - Pushing the (bottom) edge of the	at the McDonnell Douglas Research Laboratories
design. Volume 1: Methodology manual	envelope	p 549 N88-23135
[AD-A191314] p 530 N88-22906	[AIAA PAPER 88-2076] p 511 A88-38703	FLIGHT TIME
FLIGHT ENVELOPES	F-15E flight test program overview - March 1988	General aviation activity and avionics survey: 1986
Flight testing a V/STOL aircraft to identify a full-envelope	[AIAA PAPER 88-2077] p 511 A88-38704	data [AD-A189986] p 476 N88-22003
aerodynamic model	T-46A final report [AIAA PAPER 88-2092] p 511 A88-38709	FLIGHT VEHICLES
[AIAA PAPER 88-2134] p 512 A88-38731	Development of an integrated set of research facilities	Computer vision for flight vehicles in landing
X-31 - Through the grape barrier highly maneuverable fighter aircraft p 515 A88-41250	for the support of research flight test	approach p 527 A88-39485
fighter aircraft p 515 A88-41250  Multiple model parameter adaptive control for in-flight	[AIAA PAPER 88-2096] p 535 A88-38712	FLOW CHARACTERISTICS
simulation	Using GPS to enhance the DT&E ranges	The use of optimization technique and through flow analysis for the design of axial flow compressor stages
[AD-A190568] p 537 N88-22044	[AIAA PAPER 88-2098] p 536 A88-38713 Flight test imagery - Getting more for less	p 477 A88-37112
FLIGHT HAZARDS	[AIAA PAPER 88-2102] p 505 A88-38714	Time-dependent structure in wing-body junction flows
Bibliography of icing on aircraft (status 1987)	AFTI/F-111 Mission Adaptive Wing flight research	p 484 A88-38988
[DFVLR-MITT-87-18] p 502 N88-22876	program	The turbulence characteristics of a single impinging jet
Standardized ice accretion thickness as a function of	[AIAA PAPER 88-2118] p 511 A88-38719	through a crossflow p 545 A88-39012 Experimental investigation of topological structures in
cloud physics parameters [ESA-TT-1080] p 553 N88-23346	Joint Tactical Information Distribution System (JTIDS)	three-dimensional separated flow p 486 A88-39970
FLIGHT INSTRUMENTS	class 2 terminal flight test [AIAA PAPER 88-2119] p 505 A88-38720	Modelling the influence of small surface discontinuities
Geometric modeling of flight information for graphical	AQM-127A full scale engineering development Flight	in turbulent boundary layers
cockpit display	Test Program	[AIAA PAPER 88-2594] p 546 A88-40759
[AD-A190484] p 537 N88-22043	[AIAA PAPER 88-2121] p 511 A88-38722	Flow quality of NAL two-dimensional transonic wind
Basic design studies for the realization of liquid crystal	A flexible computer program for aircraft flight test	tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction
display systems in aircraft	performance [AIAA PAPER 88-2125] p 553 A88-38725	[NASA-TT-20209] p 539 N88-22911
[VA-87-001] p 521 N88-22900	A new method to confirm category III autoland	FLOW DISTRIBUTION
FLIGHT PATHS  Numerical calculations of a class of optimal flight	performance	Hover suckdown and fountain effects encountered
trajectories p 553 A88-38178	[AIAA PAPER 88-2126] p 505 A88-38726	by V/STOL aircraft
Geometric modeling of flight information for graphical	A real-time aerodynamic analysis system for use in	[SAE PAPER 872305] p 477 A88-37177 Calculation of external-internal flow fields for
cockpit display	flight [AIAA PAPER 88-2128] p 512 A88-38728	mixed-compression inlets p 479 A88-37353
[AD-A190484] p 537 N88-22043	Simulation in support of flight test - In retrospect	The Basic Aerodynamics Research Tunnel - A facility
FLIGHT SAFETY		
and the second s	[AIAA PAPER 88-2130] p 512 A88-38730	dedicated to code validation
Avionics for transport aircraft - Current development		dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910
status p 520 A88-41098	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing
status p 520 A88-41098 FLIGHT SIMULATION	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter
status p 520 A88-41098	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-turnel wall
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a
status p 520 A88-41098 FLIGHT SIMULATION Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Model selection for the multiple model adaptive algorithm for in-flight simulation [AD-A189715] p 515 N88-22022	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel inorthwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A18964] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator p 553 A88-38179	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulation p 553 A88-38179  Simulation in support of flight test - In retrospect	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test [AIAA PAPER 88-2185] p 474 A88-38754 Design, construction and flight testing the Spirit of St.	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator p 553 A88-38179  Simulation in support of flight test - In retrospect  [AIAA PAPER 88-2130] p 512 A88-38730  The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator in support of flight test - In retrospect  [AIAA PAPER 88-2130] p 512 A88-38730  The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration  [AIAA PAPER 88-2045] p 536 A88-39525	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2157] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test [AIAA PAPER 88-2185] p 474 A88-38754 Design, construction and flight testing the Spirit of St. Louis	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator in support of flight test - In retrospect  [AIAA PAPER 88-2130] p 512 A88-38730  The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration  [AIAA PAPER 88-2045] p 536 A88-39525  Developing a wide field of view HMD for simulators	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-188 subsonic aircraft [AIAA PAPER 88-2157] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test [AIAA PAPER 88-2185] p 474 A88-38754 Design, construction and flight testing the Spirit of St. Louis [AIAA PAPER 88-2187] p 557 A88-38755 Development of a mobile research flight test support capability	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Transonic Navier-Stokes computations of
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator p 553 A88-38179  Simulation in support of flight test In retrospect  [AIAA PAPER 88-2130] p 512 A88-38730  The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration  [AIAA PAPER 88-2045] p 536 A88-39525  Developing a wide field of view HMD for simulators —  Helmet Mounted Display p 520 A88-41367	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test [AIAA PAPER 88-2185] p 474 A88-38754 Design, construction and flight testing the Spirit of St. Louis [AIAA PAPER 88-2187] p 557 A88-38755 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Transonic Navier-Stokes computations of strake-generated vortex interactions for a fighter-like
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator p 553 A88-38179  Simulation in support of flight test - In retrospect  [AIAA PAPER 88-2130] p 512 A88-38730  The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration  [AIAA PAPER 88-2045] p 536 A88-39525  Developing a wide field of view HMD for simulators  Helmet Mounted Display p 520 A88-41367  First flight simulator test of the head-up display for NAL	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test [AIAA PAPER 88-2185] p 474 A88-38754 Design, construction and flight testing the Spirit of St. Louis [AIAA PAPER 88-2187] p 557 A88-38755 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Techniques used in the F-14 variable-sweep transition	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Transonic Navier-Stokes computations of
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator in support of flight test - In retrospect  [AIAA PAPER 88-2130] p 553 A88-38179  Simulation in support of flight test - In retrospect  [AIAA PAPER 88-2130] p 553 A88-38730  The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration  [AIAA PAPER 88-2045] p 536 A88-39525  Developing a wide field of view HMD for simulators  Helmet Mounted Display p 520 A88-41367  First flight simulator test of the head-up display for NAL QSTOL experimental aircraft (ASUKA)	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test [AIAA PAPER 88-2185] p 474 A88-38754 Design, construction and flight testing the Spirit of St. Louis [AIAA PAPER 88-2187] p 557 A88-38755 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Techniques used in the F-14 variable-sweep transition flight experiment	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Transonic Navier-Stokes computations of strake-generated vortex interactions for a fighter-like configuration
status p 520 A88-41098  FLIGHT SIMULATION  Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator  [SAE PAPER 872356] p 509 A88-37218  Model selection for the multiple model adaptive algorithm for in-flight simulation  [AD-A189715] p 515 N88-22022  Effects of update and refresh rates on flight simulation visual displays  [NASA-TM-100415] p 516 N88-22033  Application of eigenstructure assignment techniques in the design of a longitudinal flight control system  [AD-A189644] p 528 N88-22039  Multiple model parameter adaptive control for in-flight simulation  [AD-A190568] p 537 N88-22044  FLIGHT SIMULATORS  The modelling technique of the flight system in flight simulator in support of flight test - In retrospect  [AIAA PAPER 88-2130] p 553 A88-38730  The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration  [AIAA PAPER 88-2045] p 536 A88-39525  Developing a wide field of view HMD for simulators  Helmet Mounted Display p 520 A88-41367  First flight simulator test of the head-up display for NAL QSTOL experimental aircraft (ASUKA)	[AIAA PAPER 88-2130] p 512 A88-38730 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735 Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 Reliability and maintainability evaluation during flight test [AIAA PAPER 88-2185] p 474 A88-38754 Design, construction and flight testing the Spirit of St. Louis [AIAA PAPER 88-2187] p 557 A88-38755 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Techniques used in the F-14 variable-sweep transition	dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall [AIAA PAPER 88-2029] p 481 A88-37932 An experimental investigation of flowfield about a multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937 Adaptation of flexible wind tunnel walls for supersonic flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 Navier-Stokes computation of flow around a round-edged double-delta wing [AIAA PAPER 88-2560] p 494 A88-40767 Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Transonic Navier-Stokes computations of strake-generated vortex interactions for a fighter-like configuration [NASA-TM-100009] p 497 N88-22010

series turbofan [AIAA PAPER 88-2078]

p 513 A88-38763

Turbulent reacting flows and supersonic combustion [AD-A189690] p 541 N88-22115

FLIGHT STABILITY TESTS
Slability flight test verification by modal separation
[AIAA PAPER 88-2129] p 512 A88-38

p 512 A88-38729

On the prediction of highly vortical flows using an Euler	Water facilities in retrospect and prospect: An	Some aspects of the reliability analysis of aircraft
equation model, part 2 [AD-A190245] p 547 N88-22305	illuminating tool for vehicle design p 539 N88-23126 Qualification of a water tunnel for force measurements	structures p 544 A88-38181
Experimental investigation of the transonic flow at the	on aeronautical models p 539 N88-23128	Improving the reliability of silicon nitride - A case study p 540 A88-38316
leeward side of a delta wing at high incidence	Flow visualization study of vortex manipulation on fighter	FREE FLIGHT
(LR-518) p 499 N88-22861	configurations at high angles of attack	Use of dynamically scaled models for studies of the
Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel	p 549 N88-23130 Experimental investigation of Hover flowfields in water	high-angle-of-attack behavior of airplanes
test pressure data report	at the McDonnell Douglas Research Laboratories	p 535 A88-38692
[NASA-CR-177343-VOL-1] p 500 N88-22866	p 549 N88-23135	FREE FLOW  On hypersonic transition testing and prediction
Propulsion and airframe aerodynamic interactions of	Water flow visualisation of a ramrocket combustion chamber p 549 N88-23138	[AIAA PAPER 88-2007] p 532 A88-37916
supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report	chamber p 549 N88-23138 The ONERA water tunnels test possibilities for flow	An experimental investigation of flowfield about a
[NASA-CR-177343-VOL-2] p 500 N88-22867	visualization in aeronautical and Naval domains	multielement airfoil
Propulsion and airframe aerodynamic interactions of	p 550 N88-23139	[AIAA PAPER 88-2035] p 481 A88-37937
supersonic V/STOL configurations. Volume 4: Summary	La Recherche Aerospatiale, bimonthly bulletin, number	FREE VIBRATION  Development of a block Lanczos algorithm for free
[NASA-CR-177343-VOL-4] p 500 N88-22868 Vortex breakdown and control experiments in the	1987-3, 238/May-June [ESA-TT-1075] p 550 N88-23161	vibration analysis of spinning structures
Ames-Dryden water tunnel p 549 N88-23127	FLUID DYNAMICS	p 545 A88-40117
Short duration flow establishment on a profile in a	Review and assessment of the HOST turbine heat	FREQUENCIES
Water-Ludwieg-Tunnel p 549 N88-23134	transfer program p 526 N88-22431	Minimum weight design of rotorcraft blades with multiple
Experimental investigation of Hover flowfields in water	Tip vortices of isolated wings and helicopter rotor blades	frequency and stress constraints [NASA-TM-100569] p 517 N88-22892
at the McDonnell Douglas Research Laboratories p 549 N88-23135	[AD-A191336] p 501 N88-22874	FRICTION P 517 No6-22692
FLOW GEOMETRY	Qualification of a water tunnel for force measurements	Analytical study of friction and heat transfer in the vicinity
The Basic Aerodynamics Research Tunnel - A facility	on aeronautical models p 539 N88-23128	of a three-dimensional critical point at low and moderate
dedicated to code validation	FLUID FLOW	Reynolds numbers p 483 A88-38847
[AIAA PAPER 88-1997] p 531 A88-37910 Measurement of leading edge vortices from a delta wing	Modal forced response of propfans in yawed flow p 551 N88-23253	FRICTION FACTOR
using a three component laser velocimeter	FLUID MECHANICS	Turbulent friction on a delta wing p 480 A88-37657
[AIAA PAPER 88-2024] p 544 A88-37929	Research and technology	FUEL CONSUMPTION  The initial calculation of range and mission fuel during
Visualization and wake surveys of vortical flow over a	[NASA-TM-100172] p 558 N88-22851	conceptual design aircraft design
delta wing p 482 A88-38377	FLUTTER	[LR-525] p 517 N88-22889
Flow in out-of-plane double S-bends p 484 A88-39011	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a	NASA advanced turboprop research and concept
FLOW MEASUREMENT	dynamic windtunnel model	validation program
Experimental study of a supersonic turbulent boundary	[PB88-149885] p 528 N88-22038	[NASA-TM-100891] p 526 N88-22902 FUEL PUMPS
layer using a laser Doppler anemometer	Development of aeroelastic analysis methods for	Control of an aircraft electric fuel pump drive
p 485 A88-39623	turborotors and propfans, including mistuning	p 524 A88-39133
Aerodynamic investigation by infrared imaging [AIAA PAPER 88-2523] p 545 A88-40713	p 551 N88-23244 Application of Navier-Stokes analysis to stall flutter	FUEL TANKS
Visualization and anemometry analyses of forced	p 530 N88-23249	Development and evaluation of an airplane fuel tank
unsteady flows about an X-29 model	FLUTTER ANALYSIS	ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions
[AIAA PAPER 88-2570] p 490 A88-40741	Aircraft flight flutter testing at the NASA Ames-Dryden	[AD-A190408] p 515 N88-22025
Nonintrusive measurements of vortex flows on delta wings in a water tunnel	Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702	FUEL-AIR RATIO
[AIAA PAPER 88-2595] p 493 A88-40760	Analysis of limit cycle flutter of an airfoil in incompressible	Development of a variational method for chemical kinetic
Boundary-layer and wake measurements on a swept,	flow p 546 A88-41219	sensitivity analysis p 541 A88-38490 FULL SCALE TESTS
circulation-control wing	A computational procedure for automated flutter	Aerodynamic flow quality and acoustic characteristics
[NASA-TM-89426] p 497 N88-22013	analysis p 530 N88-23250	of the 40- by 80-foot test section circuit of the National
Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular	Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254	Full-Scale Aerodynamic Complex
planform blades at an advance ratio of 0.30	Supersonic axial-flow fan flutter p 552 N88-23255	[SAE PAPER 872328] p 530 A88-37197
[NASA-TM-100543] p 497 N88-22015	FLY BY WIRE CONTROL	Special report on Bell ACAP full-scale aircraft crash test
LOW RESISTANCE	A study of digital fly-by-wire control system design for	[SAE PAPER 872362] p 509 A88-37223
Turbulent friction on a delta wing p 480 A88-37657 FLOW THEORY	elastic aircraft p 527 A88-38191 FBW system and control law of the T-2 CCV	AQM-127A full scale engineering development Flight
Numerical separation models p 480 A88-37653	p 528 A88-40528	Test Program
LOW VELOCITY	FOAMS	[AIAA PAPER 88-2121] p 511 A88-38722
Axisymmetric turbulent compressible jet in subsonic	Soft-ground aircraft arresting systems	Fluid mechanics of dynamic stall. II - Prediction of full scale characteristics p 485 A88-39512
coflow p 480 A88-37665	[AD-A190838] p 539 N88-22912	FUSELAGES
Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall	FOG Fog persistence above some airports of the north-Italian	New structural technologies for the Dornier 328
[AIAA PAPER 88-2029] p 481 A88-37932	plains p 552 A88-38372	fuselage p 473 A88-37297
LOW VISUALIZATION	FOILS (MATERIALS)	with a simulated fuselage undersurface
Development of the University of Texas at Arlington	Piezo-electric foils as a means of sensing unsteady	p 484 A88-38986
Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913	surface forces on flow-around bodies p 483 A88-38976	Experimental comparison of lightning simulation
An experimental investigation of the aerodynamic	FOREBODIES	techniques to CV-580 airborne lightning strike
characteristics of slanted base ogive cylinders using	Visualization techniques for studying high angle of attack	measurements [AD-A190576] p 552 N88-22496
magnetic suspension technology	separated vortical flows	[/ID ///003/0] p 332   1400-22430
[AIAA PAPER 88-2011] p 481 A88-37919 Visualization techniques for studying high angle of attack	(AIAA PAPER 88-2025) p 544 A88-37930	G
separated vortical flows	Further analysis of wing rock generated by forebody vortices	G
[AIAA PAPER 88-2025] p 544 A88-37930	[AIAA PAPER 88-2597] p 494 A88-40768	GAS DYNAMICS
Visualization and wake surveys of vortical flow over a	FORTRAN	Investigation of combustion in large vortices
delta wing p 482 A88-38377  LDV measurements on impinging twin-jet fountain flows	A description of an automated database comparison	[AD-A190406] p 541 N88-22121
with a simulated fuselage undersurface	program	Research sensors p 548 N88-22430 GAS GUNS
p 484 A88-38986	[NASA-TM-100609] p 554 N88-23463	Ultrasonic Time-Of-Flight Diffraction (TOFD)
Time-dependent structure in wing-body junction flows	FRACTIONATION  Turbine fuels from tar sands bitumen and heavy oil.	measurements of crack depths in an acceleration reservoir
p 484 A88-38988	Volume 2, phase 3: Process design specifications for a	of a high velocity research gun
Experimental investigation of topological structures in three-dimensional separated flow p 486 A88-39970	turbine fuel refinery charging San Ardo heavy crude oil	[DE88-006644] p 538 N88-22907
Flow visualization and pressure distributions for an	[AD-A190120] p 543 N88-23011	GAS TEMPERATURE Research sensors p 548 N88-22430
alf-body hypersonic aircraft p 487 A88-40601	FRACTURE MECHANICS	GAS TURBINE ENGINES
Visualization and anemometry analyses of forced	Lewis Structures Technology, 1988. Volume 2: Structural Mechanics	Gas turbines challenge ceramic technology
unsteady flows about an X-29 model	[NASA-CP-3003-VOL-2] p 548 N88-22382	p 540 A88-37430
[AIAA PAPER 88-2570] p 490 A88-40741 Visualisation of the flow at the tip of a high speed axial	Mode 2 fracture mechanics p 548 N88-22418	Life of gas turbine engine disks with cracks
flow turbine rotor	A study of failure characteristics in thermoplastic	p 544 A88-37549 Combustion noise from gas turbine aircraft engines
[AD-A189928] p 546 N88-22300	composite material	measurement of far-field levels p 555 A88-39708

Gas turbines challenge ceramic technology
p 540 A88-37430

p 542 N88-22940

FRACTURE STRENGTH

[AD-A190613]

Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a

p 547 N88-22320

rectangular duct [AD-A190772]

p 555 A88-39708

p 524 A88-40563

measurement of far-field levels p 555 A88-39708

The role of electron microscopp in gas turbine materials development p 545 A88-40327

Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563

measurement of far-field levels

Review and assessment of the HOST turbine heat	GROOVES	Fatigue damage modeling for coated single crystal
transfer program p 526 N88-22431	Riblet drag reduction at flight conditions	superalloys p 542 N88-22427
Evaluation of ceramic thermal barrier coatings for gas	[AIAA PAPER 88-2554] p 494 A88-40764	Model study of thermal stresses in gas-turbine blades
turbine engine components	GROUND EFFECT (AERODYNAMICS)	with protective coating p 542 N88-22989
[ETN-88-91947] p 543 N88-22998	Hover suckdown and fountain effects encountered	HEAT SHIELDING
GAS TURBINES	by V/STOL aircraft	Dependence of structure of stabilized ZrO2 coatings on
Research as part of the Air Force in aero propulsion	[SAE PAPER 872305] p 477 A88-37177	condensation rate p 543 N88-22990
	,	HEAT TRANSFER
technology (AFRAPT) program	Hot gas recirculation in V/STOL [SAE PAPER 872306] p 477 A88-37178	Heating requirements and nonadiabatic surface effects
[76 7100000]		for a model in the NTF cryogenic wind tunnel
Small engine components test facility turbine testing	Propulsion-induced effects caused by out-of-ground	[AIAA PAPER 88-2044] p 534 A88-37944
cell	effects	Analytical study of friction and heat transfer in the vicinity
[NASA-TM-100887] p 525 N88-22037	[SAE PAPER 872307] p 477 A88-37179	of a three-dimensional critical point at low and moderate
Comparison of different kinds of compact crossflow heat	Effect of ground proximity on the aerodynamic	Reynolds numbers p 483 A88-38847
exchangers	characteristics of the STOL aircraft	Computational study of the unsteady flow due to wakes
[ESA-TT-1076] p 550 N88-23169	[SAE PAPER 872308] p 477 A88-37180	passing through a channel p 483 A88-38984
GAS-GAS INTERACTIONS	Numerical investigation of a jet in ground effect with a	Review and assessment of the HOST turbine heat
Numerical and experimental investigation of multiple		
shock wave/turbulent boundary layer interactions in a	crossflow   SAE PAPER 872344   p 478 A88-37210	
rectangular duct		HEAT TRANSFER COEFFICIENTS
[AD-A190772] p 547 N88-22320	Turbulence and fluid/acoustic interaction in impinging	Heat transfer modeling of jet vane Thrust Vector Control
GEARS	jets	(TVC) systems
Addendum-dedendum type circular-arc gears for	[SAE PAPER 872345] p 478 A88-37211	[AD-A190106] p 524 N88-22034
aero-engine accessory drive gearbox - A critical analysis	Wind tunnel investigation of wing-in-ground effects	HELICOPTER CONTROL
of strength-to-weight ratio p 545 A88-40280	[AIAA PAPER 88-2527] p 488 A88-40716	A millimeter-wave low-range radar altimeter for
GENERAL AVIATION AIRCRAFT	Numerical simulation of wings in steady and unsteady	helicopter applications - Experimental results
Wake rake studies behind a swept surface, canard	ground effects	p 519 A88-39496
		The controlled system as a system with nonholonomic
aircraft LAIAA PAPER 88-25521 p 489 A88-40732	(**************************************	constraints - The case of a helicopter
	GROUND SUPPORT SYSTEMS	p 528 A88-39622
GEOMETRICAL THEORY OF DIFFRACTION	Development of a mobile research flight test support	Servo-actuator control for sampled-data feedback
ILS glidescope evaluation of imperfect terrain	capability	disturbance rejection helicopters
p 506 A88-39135	[NASA-TM-100428] p 506 N88-22883	[ESA-TT-1002] p 529 N88-22903
GLIDE PATHS	GROUND TESTS	HELICOPTER DESIGN
ILS glidescope evaluation of imperfect terrain	The NASA Integrated Test Facility and its impact on	Technology for advanced helicopters
p 506 A88-39135	flight research	
GLOBAL POSITIONING SYSTEM	[AIAA PAPER 88-2095] p 535 A88-38711	1
Institute of Navigation, Technical Meeting, 1st, Colorado	Air Force One replacement program - An application	
Springs, CO, Sept. 21-25, 1987, Proceedings	of acquisition streamlining and Federal Aviation	NOTAR - The tail that wags the dog NO TAIl Rotor
p 502 A88-37376	Administration Certification	helicopter p 510 A88-38696
GPS overview -The operator's perspective	[AIAA PAPER 88-2123] p 474 A88-38723	Analysis of performance measurement results of
p 502 A88-37377	GUIDE VANES	propeller aircraft. I - Flight performance
GPS phase III multi-channel user equipment	Test stand performance of a convertible engine for	p 514 A88-39481
p 503 A88-37378	advanced V/STOL and rotorcraft propulsion	Rising to the challenge - Research at AATD p 475 A88-40555
Features and capabilities of the DOD standard GPS	[SAE PAPER 872355] p 523 A88-37217	1987 Technical Committee Highlights - The year in
receivers for aircraft and seaborne applications	GUST ALLEVIATORS	review Rotorcraft research and development
p 503 A88-37379		
p 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS	Design of an integrated control system for flutter margin	p 475 A88-40558
p 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a	p 475 A88-40558 Research and Development at Boeing Helicopters
p 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS  user equipment aboard the range tracking ships USNS  Observation Island and USNS Redstone	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560
p 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 HELICOPTER ENGINES
p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 Reference trajectories from GPS measurements	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 <b>HELICOPTER ENGINES</b> Development and qualification of S-76B category 'A'
p 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 <b>HELICOPTER ENGINES</b> Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds
p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 Reference trajectories from GPS measurements	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 <b>HELICOPTER ENGINES</b> Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point
p 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727
p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 Reference trajectories from GPS measurements p 503 A88-37386 A GPS hover position sensing system	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION A panel method based on velocity potential to compute	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds
p 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION A panel method based on velocity potential to compute	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727
p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 Reference trajectories from GPS measurements p 503 A88-37386 A GPS hover position sensing system p 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127   p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276
p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 Reference trajectories from GPS measurements p 503 A88-37386 A GPS hover position sensing system p 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393 The Canadian Marconi Company GPS receiver - Its	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290  HARMONICS	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37397	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37397  Integration of GPS receivers into existing inertial	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems  [ETN-88-91886] p 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS  Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems P 504 A88-37399	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems P 504 A88-37399  A fully integrated GPS/Doppler/inertial navigation	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 504 A88-37397 Integration of GPS receivers into existing inertial navigation systems A tully integrated GPS/Doppler/inertial navigation system P 504 A88-37400	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems  [ETN-88-91886] p 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042  HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 8723211 p 508 A88-37190	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37397  Integration of GPS receivers into existing inertial navigation system P 504 A88-37399  A fully integrated GPS/Doppler/inertial navigation system P 504 A88-37400  GPS integration with low-cost inertial navigation unit	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 8723211 p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems p 504 A88-37399 A fully integrated GPS/Doppler/inertial navigation system GPS integration with low-cost inertial navigation unit	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37393  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 504 A88-37397 Integration of GPS receivers into existing inertial navigation systems A fully integrated GPS/Doppler/inertial navigation system GPS integration with low-cost inertial navigation unit p 504 A88-37402 T-33 aircraft demonstration of GPS aided inertial	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier III digital flight control system [SAE PAPER 872332] p 527 A88-37201	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127  p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37399  Integration of GPS receivers into existing inertial navigation system P 504 A88-37399  A fully integrated GPS/Doppler/inertial navigation system P 504 A88-37400  GPS integration with low-cost inertial navigation unit P 504 A88-37400  T-33 aircraft demonstration of GPS aided inertial navigation P 504 A88-37403	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT	p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement p 504 A88-37399 A fully integrated GPS/Doppler/inertial navigation system p 504 A88-37400 GPS integration with low-cost inertial navigation unit p 504 A88-37402 T-33 aircraft demonstration of GPS aided inertial navigation An integrated GPS/IRS design approach	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-30563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  P 503 A88-37385  Reference trajectories from GPS measurements  P 503 A88-37386  A GPS hover position sensing system  P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems  The Canadian Marconi Company GPS receiver - Its development, test, and future  P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement  P 504 A88-37397  Integration of GPS receivers into existing inertial navigation systems  A fully integrated GPS/Doppler/inertial navigation system  GPS integration with low-cost inertial navigation unit  D 504 A88-37400  T-33 aircraft demonstration of GPS aided inertial navigation  P 504 A88-37403  An integrated GPS/IRS design approach  P 504 A88-37404	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier III digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft.
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 504 A88-37397 Integration of GPS receivers into existing inertial navigation system P 504 A88-37400 GPS integrated GPS/Doppler/inertial navigation system P 504 A88-37400 GPS integration with low-cost inertial navigation unit P 504 A88-37400 A88-37403 An integrated GPS/IRS design approach P 504 A88-37404 Integration of differential GPS with INS for precise	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems  [ETN-88-91886] p 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042  HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190  A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201  HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems p 504 A88-37399 A fully integrated GPS/Doppler/inertial navigation system p 504 A88-37400 GPS integration with low-cost inertial navigation unit p 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation of differential GPS with INS for precise position, attitude and azimuth determination	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367 HEAD-UP DISPLAYS  Trends and problems of head-up display	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127   p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Experimental and analytical aerodynamics of an
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  P 503 A88-37385  Reference trajectories from GPS measurements P 503 A88-37386  A GPS hover position sensing system P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems P 504 A88-37400  GPS integrated GPS/Doppler/inertial navigation unit P 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation A integrated GPS/IRS design approach P 504 A88-37403  An integrated GPS/IRS design approach P 504 A88-37404  Integration of differential GPS with INS for precise position, attitude and azimuth determination P 504 A88-37405	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367 HEAD-UP DISPLAYS  Trends and problems of head-up display	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-30563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 504 A88-37397 Integration of GPS receivers into existing inertial navigation system P 504 A88-37400 GPS integration with low-cost inertial navigation unit P 504 A88-37402 T-33 aircraft demonstration of GPS aided inertial navigation An integrated GPS/IRS design approach P 504 A88-37403 An integration of differential GPS with INS for precise position, attitude and azimuth determination P 504 A88-37405 Differential GPS with a sequencing receiver	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042  HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201  HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367  HEAD-UP DISPLAYS  Trends and problems of head-up display p 519 A88-40534  Analytical evaluation of birdstrike against a F-16A	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 504 A88-37397 Integration of GPS receivers into existing inertial navigation system P 504 A88-37400 GPS integrated GPS/Doppler/inertial navigation system P 504 A88-37400 GPS integration with low-cost inertial navigation unit P 504 A88-37400 An integrated GPS/IRS design approach P 504 A88-37403 An integrated GPS/IRS design approach Integration of differential GPS with INS for precise position, attitude and azimuth determination P 504 A88-37405 Differential GPS with a sequencing receiver P 505 A88-37406	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARNIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872321] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367 HEAD-UP DISPLAYS  Trends and problems of head-up display p 519 A88-40534 Analytical evaluation of birdstrike against a F-16A laminated canopy	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127   p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-30575 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  HELICOPTERS
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems p 504 A88-37390  A fully integrated GPS/Doppler/inertial navigation system p 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation an integrated GPS/IRS design approach p 504 A88-37402  Integration of differential GPS with INS for precise position, attitude and azimuth determination p 504 A88-37405  Differential GPS with a sequencing receiver p 505 A88-37406  GPS integrity monitoring for commercial applications	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367 HEAD-UP DISPLAYS  Trends and problems of head-up display p 519 A88-40534 Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127  p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40554  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  HELICOPTERS Helicopter terminal approach using differential GPS with
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  P 503 A88-37385  Reference trajectories from GPS measurements  P 503 A88-37386  A GPS hover position sensing system  P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems  P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems  P 503 A88-37391  The Canadian Marconi Company GPS receiver - Its development, test, and future  P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement  P 504 A88-37397  Integration of GPS receivers into existing inertial navigation systems  A fully integrated GPS/Doppler/inertial navigation unit  P 504 A88-37400  GPS integration with low-cost inertial navigation unit  P 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation  P 504 A88-37403  An integrated GPS/IRS design approach  P 504 A88-37404  Integration of differential GPS with INS for precise position, attitude and azimuth determination  P 504 A88-37405  Differential GPS with a sequencing receiver  P 505 A88-37406  GPS integrity monitoring for commercial applications using an IRS as a reference  P 505 A88-37412	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042  HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201  HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display p 520 A88-41367  HEAD-UP DISPLAYS  Trends and problems of head-up display  p 519 A88-40534  Analytical evaluation of birdstrike against a F-16A laminated canopy  [AIAA PAPER 88-2268] p 514 A88-40688  A lightweight innovative Helmet Airborne Display And	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  HELICOPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems p 504 A88-37390  A fully integrated GPS/Doppler/inertial navigation system p 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation an integrated GPS/IRS design approach p 504 A88-37402  Integration of differential GPS with INS for precise position, attitude and azimuth determination p 504 A88-37405  Differential GPS with a sequencing receiver p 505 A88-37406  GPS integrity monitoring for commercial applications	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARNIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872321] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center Research Center P 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance [AIAA PAPER 88-2530] p 488 A88-40717  HELICOPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  P 503 A88-37385  Reference trajectories from GPS measurements  P 503 A88-37386  A GPS hover position sensing system  P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems  P 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems  P 503 A88-37391  The Canadian Marconi Company GPS receiver - Its development, test, and future  P 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement  P 504 A88-37397  Integration of GPS receivers into existing inertial navigation systems  A fully integrated GPS/Doppler/inertial navigation unit  P 504 A88-37400  GPS integration with low-cost inertial navigation unit  P 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation  P 504 A88-37403  An integrated GPS/IRS design approach  P 504 A88-37404  Integration of differential GPS with INS for precise position, attitude and azimuth determination  P 504 A88-37405  Differential GPS with a sequencing receiver  P 505 A88-37406  GPS integrity monitoring for commercial applications using an IRS as a reference  P 505 A88-37412	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127   p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance measurement p
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 503 A88-37397 Integration of GPS receivers into existing inertial navigation system P 504 A88-37399 A fully integrated GPS/Doppler/inertial navigation system P 504 A88-37400 GPS integration with low-cost inertial navigation unit P 504 A88-37402 T-33 aircraft demonstration of GPS aided inertial navigation P 504 A88-37403 An integrated GPS/IRS design approach P 504 A88-37404 Integration of differential GPS with INS for precise position, attitude and azimuth determination P 504 A88-37405 Differential GPS with a sequencing receiver P 505 A88-37406 GPS integrity monitoring for commercial applications using an IRS as a reference P 505 A88-37412 Using GPS to enhance the DT&E ranges AA8-38713	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier III digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127  p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40554  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  HELICOPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37391 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397  Integration of GPS receivers into existing inertial navigation systems p 504 A88-37400  GPS integrated GPS/Doppler/inertial navigation unit GPS integration with low-cost inertial navigation unit GPS integrated GPS/IRS design approach p 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation of differential GPS with INS for precise position, attitude and azimuth determination p 504 A88-37405  Differential GPS with a sequencing receiver p 505 A88-37406  GPS integrity monitoring for commercial applications using an IRS as a reference p 505 A88-37412  Using GPS to enhance the DT&E ranges  IAIAA PAPER 88-2098] p 536 A88-38713  Navigation by satellite - The next step for civil aviation	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885]  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886]  P 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614]  P 529 N88-22042  HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321]  A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872321]  SAE PAPER 872321]  P 508 A88-37190  A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332]  FAEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display  P 520 A88-41367  HEAD-UP DISPLAYS  Trends and problems of head-up display  P 519 A88-40534  Analytical evaluation of birdstrike against a F-16A laminated canopy  [AIAA PAPER 88-2268]  A lightweight innovative Helmet Airborne Display And Sight (HADAS)  First flight simulator test of the head-up display for NAL QSTOL experimental aircraft (ASUKA)  [DE88-751804]	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft.    - Flight performance measurement p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover   AIAA PAPER 88-2530   p 488 A88-40717  HELICOPTERS  Helicopter erminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 504 A88-37397  Integration of GPS receivers into existing inertial navigation systems p 504 A88-37399  A fully integrated GPS/Doppler/inertial navigation unit p 504 A88-37400  GPS integration with low-cost inertial navigation unit p 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation of differential GPS with INS for precise position, attitude and azimuth determination p 504 A88-37405  Differential GPS with a sequencing receiver p 505 A88-37405  GPS integrity monitoring for commercial applications using an IRS as a reference p 505 A88-37412  Using GPS to enhance the DT&E ranges IAIAA PAPER 88-2098] p 536 A88-39375	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885]  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p. 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p. 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p. 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p. 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-39481  AR8-40575 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  HELICOPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37390 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 504 A88-37399 A fully integrated GPS / Doppler / inertial navigation system P 504 A88-37400 GPS integration with low-cost inertial navigation unit P 504 A88-37400 An integrated GPS / IRS design approach P 504 A88-37403 An integrated GPS / IRS design approach P 504 A88-37405 Differential GPS with INS for precise position, attitude and azimuth determination P 504 A88-37405 Differential GPS with a sequencing receiver P 505 A88-37406 GPS integrity monitoring for commercial applications using an IRS as a reference P 505 A88-37412 Using GPS to enhance the DT&E ranges IAIAA PAPER 88-2098   P 536 A88-38713 Navigation by satellite - The next step for civil aviation P 506 A88-39375	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulatorsHelmet Mounted Display p 520 A88-41367 HEAD-UP DISPLAYS  Trends and problems of head-up display p 519 A88-40534 Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40688 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 First flight simulator test of the head-up display for NAL QSTOL experimental aircraft (ASUKA) [DE88-751804] p 521 N88-22896 HEAT EXCHANGERS  Comparison of different kinds of compact crossflow heat	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft.    - Flight performance measurement p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover   AIAA PAPER 88-2530   p 488 A88-40717  HELICOPTERS  Helicopter erminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885]  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems  [ETN-88-91886]  P 546 N88-2290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614]  P 529 N88-22042  HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321]  A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332]  P 527 A88-37201  HEAD MOVEMENT  Developing a wide field of view HMD for simulators Helmet Mounted Display  P 519 A88-41367  HEAD-UP DISPLAYS  Trends and problems of head-up display  P 519 A88-40534  Analytical evaluation of birdstrike against a F-16A laminated canopy  [AIAA PAPER 88-2268]  A lightweight innovative Helmet Airborne Display And Sight (HADAS)  First flight simulator test of the head-up display for NAL OSTOL experimental aircraft (ASUKA)  [DE88-751804]  P 521 N88-22896  HEAT EXCHANGERS  Comparison of different kinds of compact crossflow heat exchangers	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-39276 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 504 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. 1 - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance measurement results of aircraft. II - Flight performance measurement results of aircraft. II - Flight performance measurement of a A88-30457 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  HELICOPTERS Helicopter reminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 504 A88-37397  Integration of GPS receivers into existing inertial navigation systems p 504 A88-37400  GPS integrated GPS/Doppler/inertial navigation unit p 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  An integrated GPS/IRS design approach p 504 A88-37404  Integration of differential GPS with INS for precise position, attitude and azimuth determination p 504 A88-37405  Differential GPS with a sequencing receiver p 505 A88-37405  GPS integrity monitoring for commercial applications using an IRS as a reference p 505 A88-37401  Navigation by satellite - The next step for civil aviation p 506 A88-39375  GOVERNMENT PROCUREMENT  Air Force One replacement program - An application of acquisition streamlining and Federal Aviation	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872321] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127   p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-39491 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 8-2530] p 488 A88-40717  HELICOPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30 [NASA-TM-100543] p 497 N88-22015
P 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 504 A88-37397 Integration of GPS receivers into existing inertial navigation systems P 504 A88-37399 A fully integrated GPS/Doppler/inertial navigation system P 504 A88-37400 GPS integration with low-cost inertial navigation unit P 504 A88-37402 T-33 aircraft demonstration of GPS aided inertial navigation P 504 A88-37403 An integrated GPS/IRS design approach P 504 A88-37404 Integration of differential GPS with INS for precise position, attitude and azimuth determination P 504 A88-37405 Differential GPS with a sequencing receiver P 505 A88-37406 GPS integrity monitoring for commercial applications using an IRS as a reference P 505 A88-37406 GPS integrity monitoring for commercial applications using an IRS as a reference P 505 A88-37412 Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098   P 536 A88-38713   Navigation by satellite - The next step for civil aviation p 506 A88-39375  GOVERNMENT PROCUREMENT Air Force One replacement program - An application of acquisition streamlining and Federal Aviation Administration Certification	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier III digital flight control system [SAE PAPER 872322] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40556  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-40575 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717 HELICOPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30 [NASA-TM-100543] p 497 N88-22015 The effects of torque response and time delay on
P 503 A88-37379  Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385  Reference trajectories from GPS measurements p 503 A88-37386  A GPS hover position sensing system p 503 A88-37390  A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393  The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394  Helicopter terminal approach using differential GPS with vertical-axis enhancement p 504 A88-37399  A fully integrated GPS / Doppler / inertial navigation system p 504 A88-37400  GPS integration of GPS receivers into existing inertial navigation system p 504 A88-37400  GPS integrated GPS / Doppler / inertial navigation unit p 504 A88-37402  T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  An integrated GPS / IRS design approach p 504 A88-37404  Integration of differential GPS with INS for precise position, attitude and azimuth determination p 504 A88-37405  Differential GPS with a sequencing receiver p 505 A88-37405  GPS integrity monitoring for commercial applications using an IRS as a reference p 505 A88-37412  Using GPS to enhance the DT&E ranges   AAR APPER 88-2098   p 536 A88-38713  Navigation by satellite - The next step for civil aviation of acquisition streamlining and Federal Aviation Administration Certification   AIAA PAPER 88-2123   p 474 A88-38723	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290  HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042  HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872321] p 527 A88-37201  HEAD MOVEMENT  Developing a wide field of view HMD for simulatorsHelmet Mounted Display p 520 A88-41367  HEAD-UP DISPLAYS  Trends and problems of head-up display p 519 A88-40534  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  First flight simulator test of the head-up display for NAL QSTOL experimental aircraft (ASUKA) [DE88-751804] p 521 N88-22896  HEAT EXCHANGERS  Comparison of different kinds of compact crossflow heat exchangers [ESA-TT-1076] p 550 N88-23169  HEAT FLUX  Heat flux on the surface of a wedge in Mach reflection	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point   AIAA PAPER 88-2127   p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of aircraft. II - Flight performance measurement results of aircraft. II - Flight performance measurement results of aircraft. II - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-39481 A88-39491 A88-39491 FlictoPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 555 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30 [NASA-TM-100543] p 497 N88-22015 The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023
P 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone P 503 A88-37385 Reference trajectories from GPS measurements P 503 A88-37386 A GPS hover position sensing system P 503 A88-37390 A digital P-code GPS reciever and its applications to embedded systems P 503 A88-37393 The Canadian Marconi Company GPS receiver - Its development, test, and future P 503 A88-37394 Helicopter terminal approach using differential GPS with vertical-axis enhancement P 504 A88-37397 Integration of GPS receivers into existing inertial navigation systems P 504 A88-37399 A fully integrated GPS/Doppler/inertial navigation system P 504 A88-37400 GPS integration with low-cost inertial navigation unit P 504 A88-37402 T-33 aircraft demonstration of GPS aided inertial navigation P 504 A88-37403 An integrated GPS/IRS design approach P 504 A88-37404 Integration of differential GPS with INS for precise position, attitude and azimuth determination P 504 A88-37405 Differential GPS with a sequencing receiver P 505 A88-37406 GPS integrity monitoring for commercial applications using an IRS as a reference P 505 A88-37406 GPS integrity monitoring for commercial applications using an IRS as a reference P 505 A88-37412 Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098   P 536 A88-38713   Navigation by satellite - The next step for civil aviation p 506 A88-39375  GOVERNMENT PROCUREMENT Air Force One replacement program - An application of acquisition streamlining and Federal Aviation Administration Certification	Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  H  HARMONIC OSCILLATION  A panel method based on velocity potential to compute harmonically oscillating lift surface systems [ETN-88-91886] p 546 N88-22290 HARMONICS  Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system [AD-A190614] p 529 N88-22042 HARRIER AIRCRAFT  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190 A highly monitored AV-8B Harrier III digital flight control system [SAE PAPER 872322] p 527 A88-37201 HEAD MOVEMENT  Developing a wide field of view HMD for simulators	P 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560  HELICOPTER ENGINES Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Cool European low-temperature helicopter engine p 524 A88-39276 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563  HELICOPTER PERFORMANCE Flight fatigue testing of helicopters Russian book p 510 A88-37703 Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 Analysis of performance measurement results of propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. II - Flight performance p 514 A88-39481 Helicopter dotor in hover [AIAA PAPER 88-2530] p 488 A88-40717 HELICOPTERS Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Estimation of turbulence effects on sound propagation from low flying aircraft p 505 A88-39712 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30 [NASA-TM-100543] p 497 N88-22015 The effects of torque response and time delay on rotorcraft vertical axis handling qualities

p 548 N88-22430

Research sensors

HEAT RESISTANT ALLOYS

Kryptonite they are not --- anticorrosive coatings for jet ngine superalloys p 540 A88-37429

p 541 A88-40486
Life prediction modeling based on cyclic damage accumulation p 548 N88-22426

engine superalloys p 540 A88-374 Elevated-temperature Al alloys for aircraft structure

system

[AD-A190604]

of a helicopter

[NASA-TT-20251]

[ISL-CO-247/86]

p 516 N88-22029

p 556 N88-22698

p 556 N88-22713

Method and device for the detection and identification

Acoustic propagation in the low atmosphere. Experimental study and modeling by the radius method

Arizona, USA

GRAPHS (CHARTS)

GRAPHITE-EPOXY COMPOSITES

Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations

Fog persistence above some airports of the north-Italian

p 541 A88-40174

p 552 A88-38372

HUMIDITY MEASUREMENT

HYDRAULIC TEST TUNNELS

Ames-Dryden water tunnel

laver

Aircraft observation of the specific humidity and process

Vortex breakdown and control experiments in the

p 552 A88-39508

p 549 N88-23127

of the water vapor transfer in the upper mixed boundary

Inflow measurements made with a laser velocimeter on The use of the NRC/NAE water facilities in Canadian IMPACT TESTS a helicopter model in forward flight. Volume 4: Tapered aeronautical research and development KRASH parametric sensitivity study: Transport category planform blades at an advance ratio of 0.15 p 539 N88-23132 [NASA-TM-100544] p 499 N88-22863 The ONERA water tunnels test possibilities for flow LAD-A1899621 p 515 N88-22024 Tip vortices of isolated wings and helicopter rotor visualization in aeronautical and Naval domains IMPELLERS p 550 N88-23139 blades Rotordynamic forces on centrifugal pump impellers IAD-A1913361 p 501 N88-22874 HYDROCARBON COMBUSTION p 543 A88-37108 Development of a flexible and economic helicopter Development of a variational method for chemical kinetic Cascade lift ratios for radial and semiaxial rotating ngine monitoring system sensitivity analysis p 541 A88-38490 cascades p 543 A88-37110 HYDRODYNAMICS p 517 N88-22887 [PB88-165147] IMPINGEMENT Water facilities in retrospect and prospect: An Digital processing of flight data of a helicopter without illuminating tool for vehicle design HYDROSTATICS Impingement of orthogonal unsteady vortex structures p 539 N88-23126 using anti-aliasing filters on trailing aerodynamic surfaces [ESĂ-TT-1094] p 517 N88-22890 [AIAA PAPER 88-2580] p 492 A88-40749 Active control and system identification of rotordynamic Minimum weight design of rotorcraft blades with multiple **IMPLOSIONS** structure p 551 N88-23230 frequency and stress constraints HYPERSONIC AIRCRAFT Analysis for high compressible supersonic flow in [NASA-TM-100569] p 517 N88-22892 converging nozzle Flow visualization and pressure distributions for an The application of linear maximum likelihood estimation [IPPJ-860] p 500 N88-22869 p 487 A88-40601 all-body hypersonic aircraft of aerodynamic derivatives for the Bell-205 and Bell-206 IN-FLIGHT MONITORING National Aero-Space Plane IAD-A1912791 p 518 N88-22894 [AAS PAPER 87-127] A real-time aerodynamic analysis system for use in p 540 A88-41288 Airworthiness and flight characteristics test of a ski Aerothermal tests of quilted dome models on a flat plate flight assembly for the UH-60A Black Hawk helicopter [AIAA PAPER 88-2128] at a Mach number of 6.5 p 512 A88-38728 [AD-A191414] p 518 N88-22895 INASA-TP-28041 p 547 N88-22325 Development of a real-time aeroperformance analysis Experimental investigation of Hover flowfields in water HYPERSONIC FLIGHT technique for the X-29A advanced technology at the McDonnell Douglas Research Laboratories demonstrator Technologies for hypersonic flight p 549 N88-23135 p 540 A88-39419 [AIAA PAPER 88-2145] p 512 A88-38738 Acoustic characteristics of 1/20-scale model helicopter An overview of hypersonic aerothermodynamics INCIDENCE p 495 A88-41270 Experimental investigation of the transonic flow at the INASA-CR-1773551 p 557 N88-23548 HYPERSONIC FLOW leeward side of a delta wing at high incidence HELMET MOUNTED DISPLAYS An isentropic compression heated Ludwieg tube [LR-518] p 499 N88-22861 ransient wind tunnel Optical design criteria for binocular helmet-mounted INCOMPRESSIBLE FLOW displays [AIAA PAPER 88-2019] p 533 A88-37926 p 520 A88-41366 An upwind differencing scheme for the time-accurate incompressible Navier-Stokes equations Developing a wide field of view HMD for simulators ---PNS calculations of hypersonic transitional flow over Helmet Mounted Display p 520 A88-41367 [AIAA PAPER 88-2583] p 492 A88-40752 An integrated approach to helmet display system [AIAA PAPER 88-2565] p 490 A88-40738 Analysis of limit cycle flutter of an airfoil in incompressible Computational validation of a parabolized Navier-Stokes p 520 A88-41368 flow p 546 A88-41219 HIGH REYNOLDS NUMBER solver on a sharp-nose cone at hypersonic speeds INDUCTION (MATHEMATICS) High Reynolds number, low Mach number, steady flow [AIAA PAPER 88-2566] p 490 A88-40739 field calculations over a NACA 0012 airfoil using The use of rule induction to assist in the diagnosis of HYPERSONIC SPEED avionic circuit board defects Navier-Stokes and interactive boundary layer theory A forecast of new test capabilities using Magnetic [ETN-88-92077] [AD-A189871] p 496 N88-22005 Suspension and Balance Systems HIGH SPEED [AIAA PAPER 88-2013] **INELASTIC STRESS** p 532 A88-37921 Civil applications of high speed rotorcraft and powered HYPERSONIC VEHICLES Specialty three-dimensional finite element analysis lift aircraft configurations (SAE PAPER 872372) p 548 N88-22393 An overview of hypersonic aerothermodynamics MHOST: An efficient finite element program for inelastic p 501 A88-37226 p 495 A88-41270 HIGH TEMPERATURE GASES analysis of solids and structures p 525 N88-22394 HYPERSONIC WIND TUNNELS Hot gas recirculation in V/STOL **INERTIAL NAVIGATION** Development of the University of Texas at Arlington [SAE PAPER 872306] p 477 A88-37178 Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-37376 Aerodynamics Research Center Factors affecting the temperature state of the blading [AIAA PAPER 88-2002] p 531 A88-37913 of high-temperature turbines p 486 A88-40314 On hypersonic transition testing and prediction HIGH TEMPERATURE TESTS [AIAA PAPER 88-2007] Integration of GPS receivers into existing inertial p 532 A88-37916 Elevated-temperature Al alloys for aircraft structure navigation systems p 504 A88-37399 P 541 A88-40486
HIGHLY MANEUVERABLE AIRCRAFT
X-31 - Through 455 CSCM Navier-Stokes thermal/aerodynamic analysis of A fully integrated GPS/Doppler/inertial navigation hypersonic nozzle flows with slot injection and wall cooling [AIAA PAPER 88-2587] system p 504 A88-37400 X-31 - Through the grape barrier --- highly maneuverable GPS integration with low-cost inertial navigation unit fighter aircraft p 493 A88-40756 p 515 A88-41250 p 504 A88-37402 HYPERVELOCITY GUNS HOLOGRAPHY T-33 aircraft demonstration of GPS aided inertial Time-Of-Flight Ultrasonic Diffraction A lightweight innovative Helmet Airborne Display And Sight (HADAS) p.520 A88-41369 (TOED) navigation p 504 A88-37403 measurements of crack depths in an acceleration reservoir p 520 A88-41369 Integration of differential GPS with INS for precise HOT CORROSION of a high velocity research oun position, attitude and azimuth determination [DE88-006644] Kryptonite they are not --- anticorrosive coatings for jet p 538 N88-22907 p 504 A88-37405 engine superallovs p 540 A88-37429 INERTIAL PLATFORMS HOT-WIRE ANEMOMETERS Flight test results of a vector-based failure detection Properties of a half-delta wing vortex and isolation algorithm for a redundant strapdown inertial p 483 A88-38985 measurement unit Time-dependent structure in wing-body junction flows ICE FLOES [AIAA PAPER 88-2172] p 553 A88-38765 Vehicles and aircraft on floating ice p 484 A88-38988 **INERTIAL REFERENCE SYSTEMS** HOVERING p 536 A88-40066 An integrated GPS/IRS design approach Hover suckdown and fountain effects --- encountered ICE FORMATION p 504 A88-37404 by V/STOL aircraft Bibliography of icing on aircraft (status 1987) [DFVLR-MITT-87-18] p 502 N GPS integrity monitoring for commercial applications [SAE PAPER 872305] p 477 A88-37177 p 502 N88-22876 using an IRS as a reference p 505 A88-37412 Results of a precision hover simulation on the one-to-one IMAGE PROCESSING INFORMATION MANAGEMENT motion Large Amplitude Research Simulator Current trend of digital map processing Information systems for quality. Experience at the [SAE PAPER 872356] p 509 A88-37218 p 506 A88-40533 Nerviano Aeritalia plant. Avionic systems and equipment Impact of bypass ratio on thrust-to-weight for V/STOL The effect of aircraft angular vibrations on the quality group [ETN-88-92274] [SAE PAPER 872348] p 523 A88-37237 of remotely sensed images p 520 A88-41096 p 557 N88-22821 A GPS hover position sensing system IMAGING TECHNIQUES INFORMATION SYSTEMS p 503 A88-37390 Flight test imagery - Getting more for less Joint Tactical Information Distribution System (JTIDS) Experimental and analytical aerodynamics of an [AIAA PAPER 88-2102] p 505 A88-38714 class 2 terminal flight test advanced rotor in hover [AIAA PAPER 88-2119] Aerodynamic investigation by infrared imaging p 505 A88-38720 I AIAA PAPER 88-25301 p 488 A88-40717 Geometric modeling of flight information for graphical [AIAA PAPER 88-2523] Experimental investigation of Hover flowfields in water p 545 A88-40713 cockpit display Effects of update and refresh rates on flight simulation at the McDonnell Douglas Research Laboratories (AD-A190484) p 537 N88-22043 visual displays [NASA-TM-100415] p 549 N88-23135 Information systems for quality. Experience at the **HUMAN TOLERANCES** p 516 N88-22033 Nerviano Aeritalia plant. Avionic systems and equipment Advanced turboprop aircraft flyover noise: Annoyance IMPACT DAMAGE Behaviour of damage tolerance of composite aircraft to counter-rotating-propeller configurations with an equal IETN-88-922741 p 557 N88-22821 number of blades on each rotor, preliminary results structures p 544 A88-38187 INFORMATION THEORY INASA-TM-1006121 p 557 N88-23547 IMPACT RESISTANCE

KRASH parametric sensitivity study: Transport category

A study of damage tolerance in curved composite

p 515 N88-22024

p 541 N88-22092

airplanes

panels

[AD-A189962]

AD-A1906171

**IMPACT STRENGTH** 

radar

Information

INFRARED IMAGERY

I AIAA PAPER 88-25231

INFRARED SIGNATURES

angular-coordinate estimates

properties

Aerodynamic investigation by infrared imaging

IR group activities at the Israel Aircraft Industries

of

complex

p 545 A88-38448

p 545 A88-40713

p 474 A88-40386

# **INJECTORS**

INJECTORS	INTERFERENCE DRAG	L
Development of a control system for an injector powered	Laser velocimeter measurements in a wing-fuselage type	A ANNUAR ROUNDARY LAYER
transonic wind tunnel	juncture 407 Non 20040	LAMINAR BOUNDARY LAYER  Boundary-layer stability analysis of NLF and LFC
[AIAA PAPER 88-2063] p 535 A88-37950	[NASA-TM-100588] p 497 N88-22012	experimental data at subsonic and transonic speeds
INLET FLOW	INVISCID FLOW	[SAE PAPER 871859] p 483 A88-38925
Calculation of external-internal flow fields for	Measurements in a three-dimensional turbulent boundary-layer p 484 A88-39000	Theoretical investigations, and correlative studies for
mixed-compression inlets p 479 A88-37353	boundary-layer p 484 A88-39000 Unsteady viscous-inviscid interaction procedures for	NLF, HLFC, and LFC swept wings at subsonic, transonic
Linear dynamics of supersonic inlet p 482 A88-38186	transonic airfoils using Cartesian grids	and supersonic speeds
Flow in out-of-plane double S-bends	[AIAA PAPER 88-2591] p 493 A88-40757	[SAE PAPER 871861] p 483 A88-38950
p 484 A88-39011	ISENTROPIC PROCESSES	Modifications to the Langley 8-foot transonic pressure
A numerical study of viscous flow in inlets and	An isentropic compression heated Ludwieg tube	tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047
augmentors	transient wind tunnel	[NASA-TM-4032] p 538 N88-22047 Aerothermal tests of quilted dome models on a flat plate
[AIAA PAPER 88-0187] p 495 A88-41092	[AIAA PAPER 88-2019] p 533 A88-37926	at a Mach number of 6.5
INLET NOZZLES	ISOLATION	[NASA-TP-2804] p 547 N88-22325
Test stand performance of a convertible engine for	Expanded envelope concepts for aircraft	Design method for laminar flow control of
advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217	control-element failure detection and identification	two-dimensional airfoils in incompressible flow. Numerical
INSPECTION	[NASA-CR-181664] p 507 N88-22886	study of LFC design concepts
Nondestructive evaluation of large scale composite	ITERATION	[DE88-751809] p 498 N88-22859
components	Application of efficient iteration scheme AF2 to computations of transonic full-potential flows over	LAMINAR FLOW
[AD-A190998] p 542 N88-22954	wing-body combinations p 481 A88-38177	Drag measurements on a body of revolution in Langley's 13-inch Magnetic Suspension and Balance System
INSTALLING	ITERATIVE SOLUTION	[AIAA PAPER 88-2010] p 532 A88-37918
Airworthiness and flight characteristics test of a ski	Contraction design for small low-speed wind tunnels	Comparison of Euler and Navier-Stokes solutions for
assembly for the UH-60A Black Hawk helicopter (AD-A1914141 p 518 N88-22895	[NASA-CR-182747] p 537 N88-22045	vortex flow over a delta wing p 485 A88-39278
[AD-A191414] p 518 N88-22895 INSTRUMENT ERRORS	,	Unsteady nonsimilar laminar compressible
Formulation of a general technique for predicting	1	boundary-layer flow over a yawed infinite circular
pneumatic attenuation errors in airborne pressure sensing	J	cylinder p 495 A88-40970
devices		LAMINAR FLOW AIRFOILS
(AIAA PAPER 88-2085) p 518 A88-38707	JET AIRCRAFT NOISE	Boundary-layer stability analysis of NLF and LFC
Impact pressure error on the EC-18B subsonic aircraft	Turbofan engine core noise source diagnostics p 524 A88-39707	experimental data at subsonic and transonic speeds
[AIAA PAPER 88-2177] p 513 A88-38748	·	[SAE PAPER 871859] p 483 A88-38925
INSTRUMENT LANDING SYSTEMS  A new method to confirm category III autoland	JET ENGINE FUELS  Turbine fuels from tar sands bitumen and heavy oil.	Oscillating airfoils: Achievements and conjectures
performance	Volume 2, phase 3: Process design specifications for a	[AD-A190490] p 496 N88-22008
[AIAA PAPER 88-2126] p 505 A88-38726	turbine fuel refinery charging San Ardo heavy crude oil	Design method for laminar flow control of two-dimensional airfoils in incompressible flow. Numerical
ILS glidescope evaluation of imperfect terrain	[AD-A190120] p 543 N88-23011	study of LFC design concepts
p 506 A88-39135	JET ENGINES	[DE88-751809] p 498 N88-22859
INTAKE SYSTEMS	Kryptonite they are not anticorrosive coatings for jet	LAMINAR HEAT TRANSFER
Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered	engine superalloys p 540 A88-37429	Heat transfer modeling of jet vane Thrust Vector Control
planform blades at an advance ratio of 0.15	Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland	(TVC) systems
[NASA-TM-100544] p 499 N88-22863	[AD-A189966] p 556 N88-22702	[AD-A190106] p 524 N88-22034
INTEGRAL EQUATIONS	JET FLOW	LAMINATES
An integral equation for the linearized supersonic flow	Hover suckdown and fountain effects encountered	Analytical evaluation of birdstrike against a F-16A
over a wing	by V/STOL aircraft	laminated canopy (AIAA PAPER 88-2268) p 514 A88-40868
[AD-A191408] p 501 N88-22875	[SAE PAPER 872305] p 477 A88-37177	Design studies of primary aircraft structures in ARALL
INTERACTIONAL AERODYNAMICS Turbulence and fluid/acoustic interaction in impinging	Numerical simulation of a subsonic jet in a crossflow (SAF PAPER 872343) p 478 A88-37209	laminates
jets	[SAE PAPER 872343] p 478 A88-37209  Numerical investigation of a jet in ground effect with a	[LR-520] p 517 N88-22888
[SAE PAPER 872345] p 478 A88-37211	crossflow	A study of failure characteristics in thermoplastic
Unsteady aerodynamic heating phenomena in the	[SAE PAPER 872344] p 478 A88-37210	composite material
interaction of shock wave/turbulent boundary layer	Unsteady features of jets in lift and cruise modes for	[AD-A190613] p 542 N88-22940
p 486 A88-40421	VTOL aircraft	LANDING AIDS
The effects of canard-wing flow-field interactions on longitudinal stability, effective dihedral and potential	[SAE PAPER 872359] p 478 A88-37220	CFRP landing flaps for the Airbus A320 p 474 A88-39416
deep-stall trim	The structure of sonic underexpanded turbulent air jets	First flight simulator test of the head-up display for NAL
[AIAA PAPER 88-2514] p 528 A88-40706	in still air [AD-A190856] p 500 N88-22870	QSTOL experimental aircraft (ASUKA)
Interactive geometry definition and grid generation for	JET IMPINGEMENT	[DE88-751804] p 521 N88-22896
applied aerodynamics	Experimental investigation of a jet impinging on a ground	LANDING GEAR
(AIAA PAPER 88-2515) p 554 A88-40707	plane in the presence of a cross flow	In-service measurements of SAAB SF-340 landing gear
Experimental and numerical study of the propeller/fixed	[SAE PAPER 872326] p 478 A88-37195	loads
wing interaction [AIAA PAPER 88-2571] p 491 A88-40742	Turbulence and fluid/acoustic interaction in impinging	[FFA-TN-1987-48] p 516 N88-22032
Impingement of orthogonal unsteady vortex structures	jets {SAE PAPER 872345} p 478 A88-37211	Soft-ground aircraft arresting systems
on trailing aerodynamic surfaces	[SAE PAPER 872345] p 478 A88-37211 The turbulence characteristics of a single impinging jet	[AD-A190838] p 539 N88-22912
[AIAA PAPER 88-2580] p 492 A88-40749	through a crossflow p 545 A88-39012	LANDING LOADS
Unsteady flow interactions between the wake of an	JET MIXING FLOW	In-service measurements of SAAB SF-340 landing gear
oscillating airfoil and a stationary trailing airfoil	Axisymmetric turbulent compressible jet in subsonic	loads [FFA-TN-1987-48] p 516 N88-22032
[AIAA PAPER 88-2581] p 492 A88-40750	coflow p 480 A88-37665	LANDING SIMULATION
Unsteady viscous-inviscid interaction procedures for	JET PROPULSION	First flight simulator test of the head-up display for NAL
transonic airfoils using Cartesian grids	A flow-transfer device with nonmetallic diaphragms for	QSTOL experimental aircraft (ASUKA)
[AIAA PAPER 88-2591] p 493 A88-40757	propulsion wind tunnel models [AIAA PAPER 88-2048] p 534 A88-37945	[DE88-751804] p 521 N88-22896
Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions	JET THRUST	LASER ANEMOMETERS
[AIAA PAPER 88-2592] p 493 A88-40758	Advances in ejector thrust augmentation	Measurement of leading edge vortices from a delta wing
Further analysis of wing rock generated by forebody	[SAE PAPER 872322] p 522 A88-37191	using a three component laser velocimeter
vortices	Pressure measurements of impinging jet with asymmetric	[AIAA PAPER 88-2024] p 544 A88-37929
[AIAA PAPER 88-2597] p 494 A88-40768	nozzle [NASA-CR-182759] p 497 N88-22011	LASER DOPPLER VELOCIMETERS  LDV measurements on impinging twin-jet fountain flows
Propulsion and airframe aerodynamic interactions of	[NASA-CR-182759] p 497 N88-22011 <b>JET VANES</b>	with a simulated fuselage undersurface
supersonic V/STOL configurations. Volume 1: Wind tunnel	Heat transfer modeling of jet vane Thrust Vector Control	p 484 A88-38986
test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866	(TVC) systems	Measurements in a three-dimensional turbulent
Propulsion and airframe aerodynamic interactions of	[AD-A190106] p 524 N88-22034	boundary-layer p 484 A88-39000
supersonic V/STOL configurations. Volume 2: Wind tunnel		Experimental study of a supersonic turbulent boundary
test force and moment data report	K	layer using a laser Doppler anemometer
[NASA-CR-177343-VOL-2] p 500 N88-22867		p 485 A88-39623
Propulsion and airframe aerodynamic interactions of	KALMAN FILTERS	Laser velocimeter measurements in a wing-fuselage type iuncture
supersonic V/STOL configurations. Volume 4: Summary	Kalman filter residual expert system	[NASA-TM-100588] p 497 N88-22012
[NASA-CR-177343-VOL-4] p 500 N88-22868	[AD-A190520] p 529 N88-22041  KARMAN VORTEX STREET	Inflow measurement made with a laser velocimeter on
INTERACTIVE CONTROL  A description of an automated database comparison	Experimental and numerical analysis of the formation	a helicopter model in forward flight. Volume 3: Rectangular
A description of an automated database comparison program	and evolution of streamwise vortices in the plane wake	planform blades at an advance ratio of 0.30
[NASA-TM-100609] p 554 N88-23463	behind a flat plate p 484 A88-39017	[NASA-TM-100543] p 497 N88-22015

SUBJECT INDEX Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863 Experimental studies of vortex flows p 551 N88-23171 INASA-CR-1828741 LASER INDUCED FLUORESCENCE Turbulent reacting flows and supersonic combustion [AD-A189690] p 541 N88-22115 LATTICES (MATHEMATICS) A numerical model of unsteady, subsonic aeroelastic behavior INASA-TM-1011261 **LEADING EDGES** Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929 Visualization and wake surveys of vortical flow over a delta wing p 482 A88-38377 Separation and reattachment near theleading edge of a thin wing p 486 A88-39967 Wing vortex-flows up into vortex breakdown - A numerical simulation [AIAA PAPER 88-2518] p 487 A88-40709 Navier Stokes computation of the flow field over delta wings with spanwise leading edge blowing [AIAA PAPER 88-2558] p 489 A88-40734 Leading edge vortex dynamics on a pitching delta (AIÃA PAPER 88-2559) p 489 A88-40735 A comparative study of differing vortex structures arising in unsteady separated flows IAIAA PAPER 88-25821 p 492 A88-40751 LIFE (DURABILITY) Life prediction modeling based on cyclic damage p 548 N88-22426 Fatigue damage modeling for coated single crystal p 542 N88-22427 superallovs LIFE CYCLE COSTS Testing new aircraft - Is there an R&M challenge? [AIAA PAPER 88-2182] p 474 A88-38752 LIFT

Prediction of vortex lift of non-planar wings by the p 485 A88-39279 leading-edge suction analogy Stall flutter analysis of propfans p 552 N88-23256

LIFT AUGMENTATION Propulsion-induced effects caused by out-of-ground effects [SAE PAPER 872307] p 477 A88-37179

A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184

Correlation of entrainment and lift enhancement for a two-dimensional propulsive wing [SAE PAPER 872325] p 477 A88-37194

LIFT DEVICES

A panel method based on velocity potential to compute harmonically oscillating lift surface systems LETN-88-918861 p 546 N88-22290

LIFT DRAG RATIO Cascade lift ratios for radial and semiaxial rotating cascades ascades p 543 A88-37110
Effects of maneuver dynamics on drag polars of the

X-29A forward-swept-wing aircraft with automatic wing camber control [AIAA PAPER 88-2144] p 527 A88-38737 Development of an airfoil of high lift/drag ratio and low

moment coefficient for subsonic flow p 495 A88-40972

LIFTING BODIES On the prospects for increasing dynamic lift

p 481 A88-38167 LIGHT AIRCRAFT Design, construction and flight testing the Spirit of St.

[AIAA PAPER 88-2187] p 557 A88-38755 LIGHTNING

Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike [AD-A1905761

p 552 N88-22496 LINEAR QUADRATIC GAUSSIAN CONTROL Analysis and design of gain scheduled control systems

[NASA-CR-182867] p 529 N88-22904 LINEARITY

Application of empirical and linear methods to VSTOL powered-lift aerodynamics

ISAE PAPER 8723411 p 479 A88-37236 Linear state space modeling of a turbofan engine [AD-A190110] p 524 N88-22035

An integral equation for the linearized supersonic flow [AD-A191408] p 501 N88-22875

The application of linear maximum likelihood estimation of aerodynamic derivatives for the Bell-205 and Bell-206 [AD-A191279] p 518 N88-22894 LININGS

High-temperature combustor liner tests in structura component response test facility p 525 N88-22383 Life assessment of combustor liner using unified constitutive models p 525 N88-22384 LIQUID CRYSTALS

Basic design studies for the realization of liquid crystal display systems in aircraft p 521 N88-22900 IVA-87-0011

LIQUID-SOLID INTERFACES

Heating requirements and nonadiabatic surface effects for a model in the NTF cryogenic wind tunnel p 534 A88-37944 [AIAA PAPER 88-2044]

LITHIUM ALLOYS Elevated-temperature Al alloys for aircraft structure p 541 A88-40486

Vehicles and aircraft on floating ice p 536 A88-40066

LOAD DISTRIBUTION (FORCES)

LOAD TESTS MHOST: An efficient finite element program for inelastic nalysis of solids and structures p 525 N88-22394 LOADS (FORCES)

Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis p 545 A88-40280

of strength-to-weight ratio Skunk Works prototyping IAIAA PAPER 88-20941 p 473 A88-38710

LOG PERIODIC ANTENNAS A role for fibre optics in antenna measurements

p 544 A88-38116 LONGITUDINAL STABILITY

The effects of canard-wing flow-field interactions on longitudinal stability, effective dihedral and potential deep-stall trim [AIAA PAPER 88-2514] p 528 A88-40706

LOUVERS Describing the source created by turbulent flow over orifices and louvers

[AD-A190254] p 556 N88-22706 LOW COST

GPS integration with low-cost inertial navigation unit p 504 A88-37402

LOW FREQUENCIES Subharmonic aliasing and its effects on the AFTI/F-16

digital flight control system [AD-A190614] p 529 N88-22042

LOW REYNOLDS NUMBER Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate

p 483 A88-38847 Revnolds numbers Numerical prediction of aerodynamic performance for low Reynolds number airfoil

[AIAA PAPER 88-2575] p 491 A88-40744 Design of low Reynolds number airfoils. I [AIAA PAPER 88-2572] p 494

p 494 A88-40765 LOW SPEED WIND TUNNELS

Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913 Drag measurements on a body of revolution in Langley's 13-inch Magnetic Suspension and Balance System

p 532 A88-37918 [AIAA PAPER 88-2010] Adaptive wall research with two- and three-dimensional models in low speed and transonic tunnels

[AIAA PAPER 88-2037] p 533 A88-37939 Wind tunnel interference on unsteady two-dimensional aerofoil motions in low speed flows p 535 A88-38169

Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045

M

**MACH NUMBER** 

Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2056] p 534 A88-37946 High Reynolds number, low Mach number, steady flow

field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005

Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911

MACH REFLECTION

Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves

p 486 A88-40375

MAGNETIC SUSPENSION

A review of Magnetic Suspension and Balance Systems [AIAA PAPER 88-2008] p.532 A88-37917 Drag measurements on a body of revolution in Langley's 13-inch Magnetic Suspension and Balance System [AIAA PAPER 88-2010] p 532 A88-37918

An experimental investigation of the aerodynamic characteristics of slanted base ogive cylinders using magnetic suspension technology

[AIAA PAPER 88-2011] p 481 A88-37919 Progress towards extreme attitude testing with Magnetic Suspension and Balance Systems [AIAA PAPER 88-2012]

p 532 A88-37920 A forecast of new test capabilities using Magnetic Suspension and Balance Systems

p 532 A88-37921 [AIAA PAPER 88-2013] Study on needs for a magnetic suspension system operating with a transonic wind tunnel

[AIAA PAPER 88-2014] p 533 A88-37922

MAINTAINABILITY

Testing new aircraft - Is there an R&M challenge?
[AIAA PAPER 88-2182] p 474 A88-38 p 474 A88-38752 Maintainability - A design parameter

[AIAA PAPER 88-2184] p 474 A88-38753 Reliability and maintainability evaluation during flight test

[AIAA PAPER 88-2185] p 474 A88-38754

MAN-COMPUTER INTERFACE

An interactive method for modifying numerical model wind forecasts p 552 A88-38679 MARKET RESEARCH

Cool European --- low-temperature helicopter engine

p 524 A88-39276 MASS FLOW

Unexpected/expected results from the Langley 20-Inch Supersonic Wind Tunnel during initial checkout [AIAA PAPER 88-1999]

p 531 A88-37911 MATHEMATICAL MODELS

Linear state space modeling of a turbofan engine p 524 N88-22035 [AD-A190110] On the prediction of highly vortical flows using an Euler equation model, part 2

[AD-A190245] p 547 N88-22305 Life assessment of combustor liner using unified constitutive models p 525 N88-22384

Fatigue damage modeling for coated single crystal superallovs p 542 N88-22427 Review and assessment of the HOST turbine heat transfer program p 526 N88-22431

Design method for laminar flow control of two-dimensional airfoils in incompressible flow. Numerical study of LFC design concepts

[DE88-751809] n 498 N88-22859 A numerical model of unsteady, subsonic aeroelastic behavior [NASA-TM-101126]

p 499 N88-22862 Aeroelastic forced analysis response turbomachinery p 526 N88-23247 p 552 N88-23256 Stall flutter analysis of propfans MAXIMUM LIKELIHOOD ESTIMATES

The application of linear maximum likelihood estimation of aerodynamic derivatives for the Bell-205 and Bell-206 [AD-A191279] p 518 N88-22894

MEASURING INSTRUMENTS

p 548 N88-22430 MECHANICAL MEASUREMENT

In-service measurements of SAAB SF-340 landing gear [FFA-TN-1987-48] p 516 N88-22032

**MECHANICAL PROPERTIES** Gas turbines challenge ceramic technology

p 540 A88-37430 METAL COATINGS Dependence of structure of stabilized ZrO2 coatings on

condensation rate p 543 N88-22990 METAL FATIGUE

Life prediction modeling based on cyclic damage accumulation p 548 N88-22426

Fatigue damage modeling for coated single crystal superalloys p 542 N88-22427 Development of a flexible and economic helicopter engine monitoring system

(PB88-165147) p 517 N88-22887 METEOROLOGICAL INSTRUMENTS

METEOPOD, an airborne system for measurements of mean wind, turbulence, and other meteorological parameters [AIAA PAPER 88-2103] p 519 A88-38715

METEOROLOGICAL PARAMETERS

METEOPOD, an airborne system for measurements of mean wind, turbulence, and other meteorological

[AIAA PAPER 88-2103] p 519 A88-38715

# **METEOROLOGICAL RADAR**

Acoustic propagation in the low atmosphere.	Development of a mobile research flight test support	PNS calculations of hypersonic transitional flow over
Experimental study and modeling by the radius method	capability	cones [AIAA PAPER 88-2565] p 490 A88-40738
[ISL-CO-247/86] p 556 N88-22713	[NASA-TM-100428] p 506 N88-22883	Computational validation of a parabolized Navier-Stokes
METEOROLOGICAL RADAR Information properties of complex radar	MODAL RESPONSE Stability flight test verification by modal separation	solver on a sharp-nose cone at hypersonic speeds
angular-coordinate estimates p 545 A88-38448	[AIAA PAPER 88-2129] p 512 A88-38729	[AIAA PAPER 88-2566] p 490 A88-40739
MICROPROCESSORS	Modal forced response of propfans in yawed flow	Numerical analysis of multiple element high lift devices by Navier Stokes equation using implicit TVD finite volume
Microprocessor control of high-speed wind tunnel	p 551 N88-23253	method
stagnation pressure [AIAA PAPER 88-2062] p 535 A88-37949	MODELS  Geometric modeling of flight information for graphical	[AIAA PAPER 88-2574] p 491 A88-40743
MICROSTRUCTURE	cockpit display	An upwind differencing scheme for the time-accurate
Dependence of structure of stabilized ZrO2 coatings on	[AD-A190484] p 537 N88-22043	incompressible Navier-Stokes equations [AIAA PAPER 88-2583] p 492 A88-40752
condensation rate p 543 N88-22990 MICROWAVE LANDING SYSTEMS	Inflow measurements made with a laser velocimeter on	Application of Navier-Stokes analysis to predict the
Analysis of a range estimator which uses MLS angle	a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15	internal performance of thrust vectoring two-dimensional
measurements	[NASA-TM-100544] p 499 N88-22863	convergent-divergent nozzles [AIAA PAPER 88-2586] p 493 A88-40755
[NASA-CR-182896] p 507 N88-22884	On the validation of a code and a turbulence model	Navier-Stokes computation of flow around a
MIDAIR COLLISIONS  Aircraft accident report: Midair collision of US Army	appropriate to circulation control airfoils	round-edged double-delta wing
U-21A, Army 18061 and Sachs Electric Company Piper	[NASA-TM-100090] p 499 N88-22864	[AIAA PAPER 88-2560] p 494 A88-40767 On the use of subcycling for solving the compressible
PA-31-350, N60SE, Independence, Missouri, January 20,	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow	Navier-Stokes equations by operator-splitting and finite
1987 [PB88-910401] p 502 N88-22877	p 550 N88-23155	element methods p 495 A88-41269
MILITARY AIRCRAFT	Computerized life and reliability modelling for turboprop	High Reynolds number, low Mach number, steady flow
The high technology test bed program - An overview	transmissions (NASA-TM-100918] p 551 N88-23220	field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory
of tactical STOL airlifters (SAF PAPER 872312) p 507 A88-37183	[NASA-TM-100918] p 551 N88-23220 MONOCULAR VISION	[AD-A189871] p 496 N88-22005
[SAE PAPER 872312] p 507 A88-37183 V/STOL and the Royal Air Force	An integrated approach to helmet display system	Transonic Navier-Stokes computations of
(SAE PAPER 872319) p 508 A88-37189	design p 520 A88-41368	strake-generated vortex interactions for a fighter-like
Advanced tactical transport needs and design	MOTION SIMULATION	configuration [NASA-TM-100009] p 497 N88-22010
implications [SAE PAPER 872337] p 473 A88-37205	Effects of update and refresh rates on flight simulation visual displays	Review and assessment of the HOST turbine hear
VSTOL design implications for tactical transports	[NASA-TM-100415] p 516 N88-22033	transfer program p 526 N88-22431
[SAE PAPER 872338] p 473 A88-37206	MOUNTAINS	Reduced order models for nonlinear aerodynamics p 501 N88-23248
Skunk Works prototyping LAIAA PAPER 88-20941 p 473 A88-38710	Geometric modeling of flight information for graphical	Application of Navier-Stokes analysis to stall flutter
[AIAA PAPER 88-2094] p 473 A88-38710 Joint Tactical Information Distribution System (JTIDS)	cockpit display [AD-A190484] p 537 N88-22043	p 530 N88-23249
class 2 terminal flight test	MRCA AIRCRAFT	NAVIGATION AIDS  T-33 aircraft demonstration of GPS aided inertia
[AIAA PAPER 88-2119] p 505 A88-38720	F-15E flight test program overview - March 1988	navigation p 504 A88-37403
Air Force One replacement program - An application of acquisition streamlining and Federal Aviation	[AIAA PAPER 88-2077] p 511 A88-38704	Computer vision for flight vehicles in landing
Administration Certification	MULTIPATH TRANSMISSION  Measurement of multipath propagation of	approach p 527 A88-3948
[AIAA PAPER 88-2123] p 474 A88-38723	electromagnetic waves in actual airport environments	Navigation and performance computer p 519 A88-40518
Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748	p 506 A88-39813	Airborne data bases - A quiet revolution
Reliability and maintainability evaluation during flight	MULTIPLEXING  Differential GPS with a sequencing receiver	p 506 A88-4108
test	p 505 A88-37406	Avionics for transport aircraft - Current developmen status p 520 A88-4109
[AIAA PAPER 88-2185] p 474 A88-38754		NAVIGATION SATELLITES
Was Orner Changing the way man flips	_	
V-22 Osprey - Changing the way man flies	N	Institute of Navigation, Technical Meeting, 1st, Colorado
V-22 Osprey - Changing the way man flies p 514 A88-39277		Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511	NASA PROGRAMS	Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737
V-22 Osprey - Changing the way man flies p 514 A68-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A68-39511 A lightweight innovative Helmet Airborne Display And	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden	Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702	Institute of Navigation, Technical Meeting, 1st, Colorado Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-37370 NEAR WAKES Wake rake studies behind a swept surface, canaro aircraft
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on	Institute of Navigation, Technical Meeting, 1st, Colorada Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737/ NEAR WAKES Wake rake studies behind a swept surface, canara aircraft [AIAA PAPER 88-2552] p 489 A88-4073.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research	Institute of Navigation, Technical Meeting, 1st, Colorada Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737/ NEAR WAKES Wake rake studies behind a swept surface, canar- aicraft [AIAA PAPER 88-2552] p 489 A88-4073. NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on	Institute of Navigation, Technical Meeting, 1st, Colorada Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLICHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test	Institute of Navigation, Technical Meeting, 1st, Colorade Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-37370  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft  [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988  [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712	Institute of Navigation, Technical Meeting, 1st, Colorada Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLICHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control	Institute of Navigation, Technical Meeting, 1st, Colorade Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737/  NEAR WAKES  Wake rake studies behind a swept surface, canarraircraft  [AIAA PAPER 88-2552] p 489 A88-4073/  NIGHT FLIGHTS (AIRCRAFT)  F-15E flight test program overview - March 1988  [AIAA PAPER 88-2077] p 511 A88-3870/  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136/  NOISE POLLUTION
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research  [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test  [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility	Institute of Navigation, Technical Meeting, 1st, Colorade Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-37370  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft  [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Park
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research  [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test  [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2168] p 536 A88-38745	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION Aircraft noise at the Grand Canyon National Park Airzona, USA p 552 A88-3972
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745  Development of a mobile research flight test support	Institute of Navigation, Technical Meeting, 1st, Colorade Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737/  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft  [AIAA PAPER 88-2552] p 489 A88-4073/  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870/  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136/  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA p 552 A88-3972/  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research  [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test  [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2168] p 536 A88-38745  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aircraft  [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT)  F-15E flight test program overview - March 1988  [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA p 552 A88-3972  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland  [AD-A189966] p 556 N88-2270  NOISE PROPAGATION
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37223 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190]	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research  [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test  [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2168] p 536 A88-38745  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  Rotorcraft research at NASA p 475 A88-30552  National Aero-Space Plane	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Aizona, USA  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequence domain formulation p 555 A88-3838.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Aizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequence domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagation.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745  Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761  Rotorcraft research at NASA p 475 A88-40552  National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288  NASA advanced turboprop research and concept validation program	Institute of Navigation, Technical Meeting, 1st, Colorade Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canariaircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT)  F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequence domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research  [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test  [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2168] p 536 A88-38745  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  Rotorcraft research at NASA p 475 A88-40552  National Aero-Space Plane  [AAS PAPER 87-127] p 540 A88-41288  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Aizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequence domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagation.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION Aircraft noise at the Grand Canyon National Parl Arizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270  NOISE PROPAGATION Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971.  NOISE REDUCTION Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research  [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test  [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2168] p 536 A88-38745  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  Rotorcraft research at NASA p 475 A88-40552  National Aero-Space Plane  [AAS PAPER 87-127] p 540 A88-41288  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  NASTRAN  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971.  NOISE REDUCTION  Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction.  [AIAA PAPER 88-2003] p 531 A88-3791.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 500 A88-37223 A GPS hover position sensing system p 500 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2198] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION Aircraft noise at the Grand Canyon National Park Aizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971.  NOISE REDUCTION Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction [AIAA PAPER 88-2003] p 51 A88-3791.  NOISE-CON 87; Proceedings of the National
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37230 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results	NASA PROGRAMS  Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2075] p 510 A88-38702  The NASA Integrated Test Facility and its impact on flight research  [AIAA PAPER 88-2095] p 535 A88-38711  Development of an integrated set of research facilities for the support of research flight test  [AIAA PAPER 88-2096] p 535 A88-38712  The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility  [AIAA PAPER 88-2168] p 536 A88-38745  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  Rotorcaft research at NASA p 475 A88-40552  National Aero-Space Plane  [AAS PAPER 87-127] p 540 A88-41288  NASA advanced turboprop research and concept validation program  [NASA-TM-100891] p 526 N88-22902  NASTRAN  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics  [NASA-CP-3003-VOL-1] p 551 N88-23226	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971.  NOISE REDUCTION  Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction.  [AIAA PAPER 88-2003] p 531 A88-3791.  NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902 NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226 NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION Aircraft noise at the Grand Canyon National Park Aizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low tlying aircraft p 555 A88-3971.  NOISE REDUCTION Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction [AIAA PAPER 88-2003] p 531 A88-3791.  NOISE-CON 87; Proceedings of the Nations Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987 p 555 A88-3970.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 MINES (ORDNANCE)	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2086] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971.  NOISE REDUCTION  Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction.  [AIAA PAPER 88-2003] p 531 A88-3791.  NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987.
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V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2190] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 MINES (ORDNANCE) Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing system [AD-A190604] p 516 N88-22029 MIXING Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902 NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226 NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Aizona, USA PAPER SCOUATION Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353 Recent developments and engineering applications of the vortex cloud method p 480 A88-37358 Numerical study of the skin friction on a spheroid at incidence p 482 A88-38376 Comparison of Euler and Navier-Stokes solutions for vortex flow over a delta wing p 485 A88-39278	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION Aircraft noise at the Grand Canyon National Parl Aizona, USA p 552 A88-3972 Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838 Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971  NOISE REDUCTION Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction [AIAA PAPER 88-2003] p 531 A88-3791  NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987  Mechanisms of active control for noise inside a vibration cylinder p 555 A88-3972  Active control of sound fields in elastic cylinders b vibrational inputs p 556 A88-3972  Active control of sound fields in elastic cylinders b vibrational inputs p 556 A88-3972  Active control of aeroacoustic mechanisms by remot thermal imaging [DE88-002612] p 538 N88-2204
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 500 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2998] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 MINES (ORDNANCE) Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing system [AD-A190604] p 516 N88-22029 MIXING Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 MIXING Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902 NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226 NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729 NAVIER-STOKES EQUATION Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353 Recent developments and engineering applications of the vortex cloud method p 480 A88-37353 Numerical study of the skin friction on a spheroid at incidence p 485 A88-38276 Comparison of Euler and Navier-Stokes solutions for vortex flow over a delta wing p 485 A88-38278 The numerical simulation of the Navier-Stokes equations	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Park Arizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3838.  Estimation of turbulence effects on sound propagatio from low flying aircraft p 555 A88-3971.  NOISE REDUCTION  Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction [AIAA PAPER 88-2003] p 531 A88-3791.  NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987.  Mechanisms of active control for noise inside a vibratin cylinder p 555 A88-3972.  Active control of sound fields in elastic cylinders b vibrational inputs p 556 A88-3972.  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-4055.  Investigation of aeroacoustic mechanisms by remot thermal imaging
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2198] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 MINES (ORDNANCE) Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing system [AD-A190604] p 516 N88-22029 MIXING Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 MIXING LENGTH FLOW THEORY Turbulent reacting flows and supersonic combustion	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2086] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902  NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Arizona, USA p 552 A88-39729  NAVIER-STOKES EQUATION Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353 Recent developments and engineering applications of the vortex cloud method p 480 A88-37358 Numerical study of the skin friction on a spheroid at incidence p 482 A88-39278 The numerical simulation of the Navier-Stokes solutions for vortex flow over a delta wing p 485 A88-39278 The numerical simulation of the Navier-Stokes equations for vortex flow over a delta wing p 485 A88-39278	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canara aircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION Aircraft noise at the Grand Canyon National Parl Aizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland [AD-4189966] p 556 N88-2270.  NOISE PROPAGATION Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3971.  NOISE REDUCTION Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction [AIAA PAPER 88-2003] p 531 A88-3791.  NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987 Active control of sound fields in elastic cylinders b vibrational inputs p 556 A88-3972.  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-4055.  Investigation of aeroacoustic mechanisms by remot thermal imaging [DE88-002612] p 538 N88-2204.  Noise assessment of unsuppressed TF-34-GE-100.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2198] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILLIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 MINES (ORDNANCE) Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing system [AD-A190604] p 516 N88-22029 MIXING Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 MIXING LENGTH FLOW THEORY Turbulent reacting flows and supersonic combustion [AD-A189690] p 541 N88-22115	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 556 N88-22902 NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226 NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Aizona, USA PAPER SP-20301-VOL-1] p 551 N88-23226 NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Aizona, USA Navier-Stokes EQUATION Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-39729 NAVIER-STOKES EQUATION Calculation of external-internal flow fields for orice of comparison of the skin friction on a spheroid at incidence p 482 A88-38376 Comparison of Euler and Navier-Stokes equations for vortex flow over a delta wing p 485 A88-39278 The numerical simulation of the Navier-Stokes equations for an F-16 configuration [AIAA PAPER 88-2507] p 487 A88-40702 Navier Stokes computation of the flow field over delta	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canaraircraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION Aircraft noise at the Grand Canyon National Park Aizona, USA p 552 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100, engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3971.  NOISE REDUCTION Optimum porosity for an inclined-hole transonic test section wall treated for edgetone noise reduction [AIAA PAPER 88-2003] p 531 A88-3791.  NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987 p 555 A88-3970.  Mechanisms of active control for noise inside a vibratin cylinder Active control of sound fields in elastic cylinders b vibrational inputs p 556 A88-3972.  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-4055.  Investigation of aeroacoustic mechanisms by remot thermal imaging [DE88-002612] p 538 N88-2204.  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.
V-22 Osprey - Changing the way man flies p 514 A88-39277 Fluid mechanics of dynamic stall. I - Unsteady flow concepts p 485 A88-39511 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 MILITARY HELICOPTERS Special report on Bell ACAP full-scale aircraft crash test [SAE PAPER 872362] p 509 A88-37223 A GPS hover position sensing system p 503 A88-37390 Almost all composite helicopter p 510 A88-38352 Rising to the challenge - Research at AATD p 475 A88-40555 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 MILITARY OPERATIONS Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 MILITARY TECHNOLOGY Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740 MILIMETER WAVES A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 MINES (ORDNANCE) Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing system [AD-A190604] p 516 N88-22029 MIXING Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 MIXING LENGTH FLOW THEORY Turbulent reacting flows and supersonic combustion [AD-A189690] p 541 N88-22115	NASA PROGRAMS Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2168] p 536 A88-38745 Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761 Rotorcraft research at NASA p 475 A88-40552 National Aero-Space Plane [AAS PAPER 87-127] p 540 A88-41288 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902 NASTRAN Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226 NATIONAL PARKS Aircraft noise at the Grand Canyon National Park, Aizona, USA  NAVIER-STOKES EQUATION Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353 Recent developments and engineering applications of the vortex cloud method p 480 A88-37358 Numerical study of the skin friction on a spheroid at incidence p 482 A88-38376 Comparison of Euler and Navier-Stokes equations for vortex flow over a delta wing p 485 A88-39278 The numerical simulation of the Navier-Stokes equations for an F-16 configuration [AIAA PAPER 88-2507] p 487 A88-40702	Institute of Navigation, Technical Meeting, 1st, Coloradi Springs, CO, Sept. 21-25, 1987, Proceedings p 502 A88-3737.  NEAR WAKES  Wake rake studies behind a swept surface, canari aicraft [AIAA PAPER 88-2552] p 489 A88-4073.  NIGHT FLIGHTS (AIRCRAFT) F-15E flight test program overview - March 1988 [AIAA PAPER 88-2077] p 511 A88-3870.  NIGHT VISION  Suppressing display cockpit reflections p 515 A88-4136.  NOISE POLLUTION  Aircraft noise at the Grand Canyon National Parl Arizona, USA  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.  NOISE PROPAGATION  Calculation of transonic rotor noise using a frequenc domain formulation p 555 A88-3972.  NOISE REDUCTION  Optimum porosity for an inclined-hole transonic tes section wall treated for edgetone noise reduction.  [AIAA PAPER 88-2003] p 531 A88-3791.  NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvani State University, State College, June 8-10, 1987.  Mechanisms of active control for noise inside a vibratin cylinder p 555 A88-3972.  Active control of sound fields in elastic cylinders b vibrational inputs  The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-3972.  Noise assessment of unsuppressed TF-34-GE-100. engine at Warfield ANG, Baltimore, Maryland [AD-A189966] p 556 N88-2270.

Describing the source created b	by turbulent flow over	0	PARALLEL PROCESSING (COMPUTERS)
orifices and louvers [AD-A190254]	+ FFC NOO 00700		Lewis Structures Technology, 1988. Volume 1: Structural
•	p 556 N88-22706	OBLIQUE WINGS	Dynamics
NONDESTRUCTIVE TESTS	mission A	Conceptual final paper on the preliminary design of an oblique flying wing SST	[NASA-CP-3003-VOL-1] p 551 N88-23226
Improving the reliability of silicon	p 540 A88-38316	[NASA-CR-182879] p 517 N88-22891	PARAMETER IDENTIFICATION
The sale of any deal, of a con-		OGIVES p 517 (488-2289)	Parametric study of supersonic STOVL flight
The role of non-destructive testin certification of civil aircraft composition		An experimental investigation of the aerodynamic	characteristics
certification of civil aircraft composi	p 545 A88-40175	characteristics of slanted base ogive cylinders using	[NASA-CR-177330] p 518 N88-22893
Named and the second of the se		magnetic suspension technology	Analysis and design of gain scheduled control
Nondestructive evaluation of large	ge scale composite	[AIAA PAPER 88-2011] p 481 A88-37919	systems [NASA-CR-182867] p 529 N88-22904
components [AD-A190998]	- 540 - 1400 - 1005 -	ONBOARD DATA PROCESSING	
•	p 542 N88-22954	An airborne realtime data processing and monitoring	PASSENGER AIRCRAFT
NONLINEAR FEEDBACK		system for research aircraft	Power supply for an easily reconfigurable connectorless passenger-aircraft entertainment system
Problems in nonlinear continuum [AD-A190538]		[AIAA PAPER 88-2165] p 506 A88-38743	p 513 A88-38800
	p 554 N88-22691	Navigation and performance computer	Dornier 328 taking shape p 514 A88-39415
NONLINEAR PROGRAMMING		p 519 A88-40518 Airborne data bases - A quiet revolution	In-service measurements of SAAB SF-340 landing gear
Numerical calculations of a cl			loads
trajectories	p 553 A88-38178	p 506 A88-41089	[FFA-TN-1987-48] p 516 N88-22032
NONLINEARITY		Development of a flexible and economic helicopter engine monitoring system	PATTERN RECOGNITION
Nonlinear wave interactions in sw		[PB88-165147] p 517 N88-22887	Method and device for the detection and identification
[NASA-CR-4142]	p 550 N88-23160	OPERATING TEMPERATURE	of a helicopter
Reduced order models for nonline		Cool European low-temperature helicopter engine	[NASA-TT-20251] p 556 N88-22698
	p 501 N88-23248	p 524 A88-39276	PERFORATED PLATES
NOSE CONES		OPTICAL EQUIPMENT	Optimum porosity for an inclined-hole transonic test
Computational validation of a parat	polized Navier-Stokes	Optical technology application in aircraft	section wall treated for edgetone noise reduction
solver on a sharp-nose cone at hype		p 474 A88-40532	[AIAA PAPER 88-2003] p 531 A88-37914
[AIAA PAPER 88-2566]	p 490 A88-40739	Optical design criteria for binocular helmet-mounted	PERFORMANCE PREDICTION
NOZZLE DESIGN		displays p 520 A88-41366	Estimation of thrust augmentor performance in V/STOL
Analysis for high compressible	supersonic flow in	Preliminary airworthiness evaluation of the UH-60A with	applications
converging nozzle		Advanced Digital Optical Control System (ADOCS)	[SAE PAPER 872323] p 522 A88-37192
[IPPJ-860]	p 500 N88-22869	[AD-A190674] p 516 N88-22030	Radial tires for aircraft? p 510 A88-38353
NOZZLE FLOW		OPTICAL RADAR	Formulation of a general technique for predicting
The ground environment created b	by high specific thrust	Optical technology application in aircraft	pneumatic attenuation errors in airborne pressure sensing
vertical land aircraft		p 474 A88-40532	devices
[SAE PAPER 872309]	p 477 A88-37181	OPTICAL REFLECTION	[AIAA PAPER 88-2085]
Application of Navier-Stokes an	alysis to predict the	Suppressing display cockpit reflections	Fluid mechanics of dynamic stall. II - Prediction of full
internal performance of thrust vector	ring two-dimensional	p 515 A88-41364	scale characteristics p 485 A88-39512
convergent-divergent nozzles		OPTIMIZATION	Flat panel display trends p 545 A88-40535
[AIAA PAPER 88-2586]	p 493 A88-40755	The use of optimization technique and through flow	Numerical prediction of aerodynamic performance for
CSCM Navier-Stokes thermal/aero	odynamic analysis of	analysis for the design of axial flow compressor stages	a low Reynolds number airfoil
hypersonic nozzle flows with slot	injection and wall	p 477 A88-37112	[AIAA PAPER 88-2575] p 491 A88-40744
cooling		Optimizing advanced propeller designs by	Stall flutter analysis of propfans p 552 N88-23256
[AIAA PAPER 88-2587]	p 493 A88-40756	simultaneously updating flow variables and design	PERFORMANCE TESTS
NUCLEAR FUELS		parameters	The Canadian Marconi Company GPS receiver - Its
Analysis for high compressible	supersonic flow in	[AIAA PAPER 88-2532] p 488 A88-40718	development, test, and future p 503 A88-37394
converging nozzle		Unsteady aerodynamics of a Wortmann FX-63-137 wing	Keys to a successful flight test
[IPPJ-860]	p 500 N88-22869	in a fluctuating wind field	[AIAA PAPER 88-2174] p 519 A88-38766
NUMERICAL ANALYSIS		[AD-A190128] p 496 N88-22006	PHOTOGRAMMETRY
Calculation of external-internal	flow fields for	Minimum weight design of rotorcraft blades with multiple	The effect of aircraft angular vibrations on the quality
mixed-compression inlets	p 479 A88-37353	frequency and stress constraints	of remotely sensed images p 520 A88-41096
Mode 2 fracture mechanics	p 548 N88-22418	[NASA-TM-100569] p 517 N88-22892	PIEZOELECTRICITY
Design method for laminar	flow control of	ORIFICES	Piezo-electric foils as a means of sensing unsteady surface forces on flow-around bodies
two-dimensional airfoils in incompress	sible flow. Numerical	Describing the source created by turbulent flow over	p 483 A88-38976
study of LFC design concepts		orifices and louvers	Piezoelectric pushers for active vibration control of
[DE88-751809]	p 498 N88-22859	[AD-A190254] p 556 N88-22706	rotating machinery p 551 N88-23229
NUMERICAL CONTROL		OSCILLATING CYLINDERS	PILOT PERFORMANCE
A highly monitored AV-8B Harrier II	digital flight control	Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike	Aircraft accident report: North Star Aviation, Inc., PA-32
system		techniques to CV-580 airborne lightning strike measurements	RT-300, N39614 and Alameda Aero Club Cessna 172.
[SAE PAPER 872332]	p 527 A88-37201	[AD-A190576] p 552 N88-22496	N75584, Oakland, California, March 31, 1987
Microprocessor control of high-s	peed wind tunnel	OSCILLATING FLOW	[PB87-910412] p 502 N88-22021
stagnation pressure	- 505	Oscillating airfoils: Achievements and conjectures	PILOT PLANTS
[AIAA PAPER 88-2062]	p 535 A88-37949	[AD-A190490] p 496 N88-22008	Turbine fuels from tar sands bitumen and heavy oil.
A study of digital fly-by-wire contro		OXIDATION RESISTANCE	Volume 2, phase 3: Process design specifications for a
elastic aircraft	p 527 A88-38191	Improving the reliability of silicon nitride - A case study	turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011
NUMERICAL FLOW VISUALIZATION	- i-4 i **	p 540 A88-38316	PILOT TRAINING
Numerical simulation of a subsonic [SAE PAPER 872343]			T-46A final report
	p 478 A88-37209	<b>D</b>	[AIAA PAPER 88-2092] p 511 A88-38709
Numerical simulation of compressil	ble flow field about	P	PITCH (INCLINATION)
complete ASKA aircraft configuration [SAE PAPER 872346]	n 470 Ago 07040		Pitch rate and Reynolds number effects on a pitching
	p 478 A88-37212	PANEL METHOD (FLUID DYNAMICS)	rectangular wing
Numerical study of the skin friction incidence		Prediction of vortex lift of non-planar wings by the	[AIAA PAPER 88-2577] p 491 A88-40746
	p 482 A88-38376	leading-edge suction analogy p 485 A88-39279	Unsteady aerodynamic forces at low airfoil pitching
The numerical simulation of the Navie for an F-16 configuration	er-Stokes equations	A panel method procedure for interference assessment	rates
(ALAA BARER OO ARAA	p 487 A88-40702	in slotted-wall wind tunnels	[AIAA PAPER 88-2579] p 492 A88-40748
Numerical simulation of wings in st		[AIAA PAPER 88-2537] p 537 A88-40721	PLANFORMS
ground effects	ous and disteady	A panel method based on velocity potential to compute	Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered
CALA A DADED OF SELEC	p 488 A88-40728	harmonically oscillating lift surface systems [ETN-88-91886] p.546 N88-22290	planform blades at an advance ratio of 0.15
A method to increase the accura		PARACHUTES p 546 N88-22290	[NASA-TM-100544] p 499 N88-22863
simulations	, o. Tollion 110W	Experimental investigation on rigid hollow hemispherical	PLASTIC AIRCRAFT STRUCTURES
( A ( A A B A B E B A A A A A A A A A A A A A	p 490 A88-40736	parachute model in accelerating and steady flow	Almost all composite helicopter p 510 A88-38352
Computational simulation of vortex g		p 482 A88-38185	PLASTICS
transonic shock/boundary layer intera-	ction	Flow past two-dimensional ribbon parachute models	Soft-ground aircraft arresting systems
	p 495 A88-40771	[AIAA PAPER 88-2524] p 488 A88-40714	[AD-A190838] p 539 N88-22912
A numerical study of viscous flo		Measurements of aerodynamic forces on unsteadily	PLUMES
augmentors	unu		The ground environment created by high specific thrust
[AIAA PAPER 88-0187]	p 495 A88-41092	PARALLEL FLOW	vertical land aircraft
NUMERICAL WEATHER FORECASTIN		LDV measurements on impinging twin-jet fountain flows	[SAE PAPER 872309] p 477 A88-37181
An interactive method for modifying		with a simulated fuselage undersurface	Unsteady features of jets in lift and cruise modes for
	p 552 A88-38679	p 484 A88-38986	VTOL aircraft (SAF PAPER 8733501
		p 700-30300	[SAE PAPER 872359] p 478 A88-37220

# **POLAR REGIONS**

POLAR REGIONS	The application of circulation control pneumatic	PRINTED CIRCUITS  The use of rule induction to assist in the diagnosis of
Vehicles and aircraft on floating ice	technology to powered-lift STOL aircraft [SAE PAPER 872335] p 508 A88-37204	ayionic circuit board defects
p 536 A88-40066	VSTOL design implications for tactical transports	[ETN-88-92077] p 521 N88-22899
POLARIZERS Suppressing display cockpit reflections		PROBABILITY THEORY
p 515 A88-41364	Civil applications of high speed rotorcraft and powered	Multiple model parameter adaptive control for in-flight
POLLUTION MONITORING	lift aircraft configurations	simulation [AD-A190568] p 537 N88-22044
Aircraft noise at the Grand Canyon National Park,	[SAE PAPER 872372] p 501 A88-37226	PROBLEM SOLVING
Arizona, USA p 552 A88-39729 POROUS WALLS	Powered-lift transport aircraft certification criteria	Water facilities in retrospect and prospect: An
Optimum porosity for an inclined-hole transonic test	status [SAE PAPER 872376] p 501 A88-37227	illuminating tool for vehicle design p 539 N88-23126
section wall treated for edgetone noise reduction	The synthesis of ejector lift/vectored thrust for STOVL	PROCESS CONTROL (INDUSTRY) Information systems for quality. Experience at the
[AIAA PAPER 88-2003] p 531 A88-37914	SAE PAPER 872378  p 523 A88-37228	Nerviano Aeritalia plant. Avionic systems and equipment
PORTABLE EQUIPMENT	Configuration E-7 supersonic STOVL fighter/attack	group
Development of a mobile research flight test support	technology program	[ETN-88-92274] p 557 N88-22821
capability [AIAA PAPER 88-2087] p 536 A88-38761	SAE PAPER 872379  p 509 A88-37229	PROGRAMMING LANGUAGES
POSITION INDICATORS	Applying vectored thrust V/STOL experience in	Geometric modeling of flight information for graphical
Development of an interactive real-time graphics system	supersonic designs [SAE PAPER 872381] p 509 A88-37230	cockpit display [AD-A190484] p 537 N88-22043
for the display of vehicle space positioning	[SAE PAPER 872381] p 509 A88-37230  A supersonic design with V/STOL capability	PROLATE SPHEROIDS
[AIAA PAPER 88-2167] p 536 A88-38744	SAE PAPER 872382   p 509 A88-37231	Numerical study of the skin friction on a spheroid at
POSITION SENSING A GPS hover position sensing system	Application of empirical and linear methods to VSTOL	incidence p 482 A88-38376
p 503 A88-37390	powered-lift aerodynamics	PROP-FAN TECHNOLOGY
Integration of differential GPS with INS for precise	[SAE PAPER 872341] p 479 A88-37236	Mach number corrections for a two-foot propeller rig in solid and slotted test sections
position, attitude and azimuth determination	Overview of the US/UK ASTOVL program	[AIAA PAPER 88-2056] p 534 A88-37946
p 504 A88-37405	SAE PAPER 872365  p 473 A88-37238	Development of aeroelastic analysis methods for
POTENTIAL FLOW  Recent developments and engineering applications of	Study of powered-lift aircraft using jump struts  IAIAA PAPER 88-2179 p 513 A88-38749	turborotors and propfans, including mistuning
the vortex cloud method p 480 A88-37358	[AIAA PAPER 88-2179] p 513 A88-38749 PREDICTION ANALYSIS TECHNIQUES	p 551 N88-23244
A comparison of numerical algorithms for unsteady	Life prediction modeling based on cyclic damage	The 2-D and 3-D time marching transonic potential flow method for propfans p 501 N88-23245
transonic flow p 480 A88-37360	accumulation p 548 N88-22426	method for propfans p 501 N88-23245 Propfan model wind tunnel aeroelastic research
An experimental investigation of flowfield about a	Fatigue damage modeling for coated single crystal	results p 501 N88-23246
multielement airfoil  (AIAA PAPER 88-2035) p 481 A88-37937	superalloys p 542 N88-22427	A computational procedure for automated flutter
[AIAA PAPER 88-2035] p 481 A88-3/93/ Application of efficient iteration scheme AF2 to	Review and assessment of the HOST turbine heat	analysis p 530 N88-23250
computations of transonic full-potential flows over	transfer program p 526 N88-22431	Modal forced response of propfans in yawed flow p 551 N88-23253
wing-body combinations p 481 A88-38177	A numerical model of unsteady, subsonic aeroelastic	Vibration and flutter analysis of the SR-7L large-scale
La Recherche Aerospatiale, bimonthly bulletin, number	behavior INASA-TM-101126   p 499 N88-22862	propfan p 551 N88-23254
1987-3, 238/May-June (FSA-TT-1075) p 550 N88-23161	[NASA-TM-101126] p 499 N88-22862 PREDICTIONS	PROPELLANT MASS RATIO
[ESA-TT-1075] p 550 N88-23161 The 2-D and 3-D time marching transonic potential flow	Flexiwall 3 SO: A second order predictive strategy for	The initial calculation of range and mission fuel during
method for propfans p 501 N88-23245	rapid wall adjustment in two-dimensional compressible	conceptual design aircraft design
Reduced order models for nonlinear aerodynamics	flow	[LR-525] p 517 N88-22889 PROPELLER BLADES
p 501 N88-23248	[NASA-CR-181662] p 498 N88-22018	Flowfield study at the propeller disks of a twin pusher,
POTENTIAL THEORY	The 2-D and 3-D time marching transonic potential flow method for propfans p 501 N88-23245	canard aircraft
A panel method based on velocity potential to compute harmonically oscillating lift surface systems	The state of the s	[AIAA PAPER 88-2511] p 514 A88-40704
[ETN-88-91886] p 546 N88-22290	Aeroelastic forced response analysis of turbomachinery p 526 N88-23247	Optimizing advanced propeller designs by
		simultaneously updating flow variables and design
POWDER METALLURGY	PRESSURE DISTRIBUTION	
Elevated-temperature Al alloys for aircraft structure	PRESSURE DISTRIBUTION  Turbulent friction on a delta wing p 480 A88-37657	parameters
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486	PRESSURE DISTRIBUTION  Turbulent friction on a delta wing p 480 A88-37657  Calculated viscous effects on airfoils at transonic	parameters [AIAA PAPER 88-2532] p 488 A88-40718
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486 POWER EFFICIENCY	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning
Elevated-temperature Al alloys for aircraft structure p 541 A88-40486 POWER EFFICIENCY Thrust efficiency of powered lift systems	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition,	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an p 487 A88-40601 On a least-energy hypothesis for the wake of	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation -	parameters  [AIAA PAPER 88-2532] p 488 A88-40718  Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253  Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254  Advanced turboprop aircraft flyover noise: Annoyance
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an p 487 A88-40601 On a least-energy hypothesis for the wake of	parameters  [AIAA PAPER 88-2532] p 488 A88-40718  Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253  Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow	parameters  [AIAA PAPER 88-2532] p 488 A88-40718  Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253  Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. [SAE P-203] p 473 A88-37176 Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180 The ground environment created by high specific thrust	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory	parameters  [AIAA PAPER 88-2532] p 488 A88-40718  Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253  Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings. [SAE P-203] p 473 A88-37176 Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180 The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181 A review of the de Havilland augmentor-wing powered-lift	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with	parameters  [AIAA PAPER 88-2532] p 488 A88-40718  Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253  Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY  Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SIPPSTREAMS
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance flight testing of a single engine powered	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-2205 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance flight testing of a single engine powered lift aircraft	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-2241 Aerothermal tests of quilted dome models on a flat plate	parameters  [AIAA PAPER 88-2532] p 488 A88-40718  Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253  Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY  Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SIPPSTREAMS
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels INASA-CR-1827471 p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SUPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS
POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180 The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181 A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Performance liight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185 Quiet Short-Haul Research Aircraft - A summary of flight	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-2241 Aerothermal tests of quilted dome models on a flat plate	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield śtudy at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS Mach number corrections for a two-foot propeller rig
POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance liight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185  Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-213] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 PRESSURE EFFECTS	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS Mach number corrections for a two-foot propeller rig in solid and slotted test sections
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180 The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181 A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Performance liight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185 Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186 Flight evaluation of an integrated control and display	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 496 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 Supersonic axial-flow fan flutter p 552 N88-23255  PRESSURE EFFECTS Modifications to the Langley 8-foot transonic pressure	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS  Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2056] p 534 A88-37946
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180 The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181 A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185 Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186 Flight evaluation of an integrated control and display system for high-precision manual landing flare of	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22045 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-28041] p 547 N88-22325 Supersonic axial-flow fan flutter p 552 N88-23255  PRESSURE EFFECTS Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS Mach number corrections for a two-foot propeller rig in solid and slotted test sections
Elevated-temperature AI alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185  Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186  Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 Supersonic axial-flow fan flutter p 552 N88-23255 PRESSURE EFFECTS Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS  Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2056] p 534 A88-37946 Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019
POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185  Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186  Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft [SAE PAPER 872316] p 508 A88-37187	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 Supersonic axial-flow fan flutter p 552 N88-23255  PRESSURE EFFECTS Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047  PRESSURE MEASUREMENT Impact pressure error on the EC-18B subsonic aircraft	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244  Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2056] p 534 A88-37946 Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019 NASA advanced turboprop research and concept
Elevated-temperature Al alloys for aircraft structure p 541 A88-40486  POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 477 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180 The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181 A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Performance liight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185 Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186 Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft [SAE PAPER 872316] p 508 A88-37187 V/STOL and the Royal Air Force	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 540 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 Supersonic axial-flow fan flutter p 552 N88-23255 PRESSURE EFFECTS Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047 PRESSURE MEASUREMENT Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704  PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742  PROPELLERS Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2056] p 534 A88-37946 Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019 NASA advanced turboprop research and concept validation program
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POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185  Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186  Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft [SAE PAPER 872316] p 508 A88-37187  V/STOL and the Royal Air Force [SAE PAPER 872321] p 508 A88-37189  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190  Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37190  Thrust efficiency of powered lift systems [SAE PAPER 872327] p 526 A88-37190  The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 527 A88-37201  A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201  Propulsion/aerodynamic integration in ASTOVL combat	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 Supersonic axial-flow fan flutter p 552 N88-23255 PRESSURE EFFECTS Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047 PRESSURE MEASUREMENT Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 PRESSURE MEASUREMENT Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 PRESSURE OSCILLATIONS Pressure measurements of impinging jet with asymmetric nozzle [NASA-CR-182759] p 497 N88-22011 PRESSURE REDUCTION Theoretical and experimental analysis of the slotted-wall flow field in a transonic wind tunnel 1 [SAE PAPER 871757] p 482 A88-38775 PRESSURE SENSORS Formulation of a general technique for predicting pneumatic attenuation errors in airborne pressure sensing devices	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547 PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704 PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742 PROPELLERS Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2561] p 534 A88-37946 Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902 Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155 PROPULSION Propulsion-induced effects caused by out-of-ground effects [SAE PAPER 872307] p 477 A88-37179 Research as part of the Air Force in aero propulsion technology (AFRAPT) program [AD-A190336] p 525 N88-22036 PROPULSION SYSTEM CONFIGURATIONS
POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196 POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176 Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180 The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181 A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184 Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185 Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186 Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft [SAE PAPER 872319] p 508 A88-37187 V/STOL and the Royal Air Force [SAE PAPER 872319] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37190 Thrust efficiency of powered lift systems [SAE PAPER 872321] p 508 A88-37200 A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201 Propulsion/aerodynamic integration in ASTOVL combat aircraft — Advanced Short Take-Off Vertical Landing	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 PRESSURE EFFECTS Modifications to the Langley 8-toot transonic pressure tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047 PRESSURE MEASUREMENT Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 PRESSURE OSCILLATIONS Pressure measurements of impinging jet with asymmetric nozzle [NASA-CR-182759] p 497 N88-22011 PRESSURE REDUCTION Theoretical and experimental analysis of the slotted-wall flow field in a transonic wind tunnel [SAE PAPER 871757] p 482 A88-38775 PRESSURE SENSORS Formulation of a general technique for predicting pneumatic attenuation errors in airborne pressure sensing devices [AIAA PAPER 88-2085] p 518 A88-38707	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547 PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704 PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742 PROPELLER SLIPSTREAMS Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2056] p 534 A88-37946 Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902 Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155 PROPULSION Propulsion-induced effects caused by out-of-ground effects [SAE PAPER 872307] p 477 A88-37179 Research as part of the Air Force in aero propulsion technology (AFRAPT) program [AD-A190336] p 525 N88-22036 PROPULSION SYSTEM CONFIGURATIONS Integrated control and display research for transition and
POWER EFFICIENCY Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37196  POWERED LIFT AIRCRAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176  Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft [SAE PAPER 872308] p 477 A88-37180  The ground environment created by high specific thrust vertical land aircraft [SAE PAPER 872309] p 477 A88-37181  A review of the de Havilland augmentor-wing powered-lift concept and its future applications [SAE PAPER 872313] p 507 A88-37184  Performance flight testing of a single engine powered lift aircraft [SAE PAPER 872314] p 507 A88-37185  Quiet Short-Haul Research Aircraft - A summary of flight research since 1981 [SAE PAPER 872315] p 508 A88-37186  Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft [SAE PAPER 872316] p 508 A88-37187  V/STOL and the Royal Air Force [SAE PAPER 872321] p 508 A88-37189  Near term enhancements of the AV-8B Harrier II [SAE PAPER 872321] p 508 A88-37190  Thrust efficiency of powered lift systems [SAE PAPER 872327] p 522 A88-37190  Thrust efficiency of powered lift systems [SAE PAPER 872327] p 526 A88-37190  The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 527 A88-37201  A highly monitored AV-8B Harrier II digital flight control system [SAE PAPER 872332] p 527 A88-37201  Propulsion/aerodynamic integration in ASTOVL combat	Turbulent friction on a delta wing p 480 A88-37657 Calculated viscous effects on airfoils at transonic speeds [AIAA PAPER 88-2027] p 481 A88-37931 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705 High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005 Contraction design for small low-speed wind tunnels [NASA-CR-182747] p 537 N88-22045 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 [NASA-TP-2804] p 547 N88-22325 Supersonic axial-flow fan flutter p 552 N88-23255 PRESSURE EFFECTS Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047 PRESSURE MEASUREMENT Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 PRESSURE MEASUREMENT Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 PRESSURE OSCILLATIONS Pressure measurements of impinging jet with asymmetric nozzle [NASA-CR-182759] p 497 N88-22011 PRESSURE REDUCTION Theoretical and experimental analysis of the slotted-wall flow field in a transonic wind tunnel 1 [SAE PAPER 871757] p 482 A88-38775 PRESSURE SENSORS Formulation of a general technique for predicting pneumatic attenuation errors in airborne pressure sensing devices	parameters [AIAA PAPER 88-2532] p 488 A88-40718 Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244 Modal forced response of propfans in yawed flow p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale propfan p 551 N88-23254 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547 PROPELLER EFFICIENCY Flowfield study at the propeller disks of a twin pusher, canard aircraft [AIAA PAPER 88-2511] p 514 A88-40704 PROPELLER SLIPSTREAMS Experimental and numerical study of the propeller/fixed wing interaction [AIAA PAPER 88-2571] p 491 A88-40742 PROPELLERS Mach number corrections for a two-foot propeller rig in solid and slotted test sections [AIAA PAPER 88-2561] p 534 A88-37946 Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019 NASA advanced turboprop research and concept validation program [NASA-TM-100891] p 526 N88-22902 Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155 PROPULSION Propulsion-induced effects caused by out-of-ground effects [SAE PAPER 872307] p 477 A88-37179 Research as part of the Air Force in aero propulsion technology (AFRAPT) program [AD-A190336] p 525 N88-22036 PROPULSION SYSTEM CONFIGURATIONS

Stability and control augmentation system of 'ASKA' | SAE PAPER 872334 | p 527 A88-37203

Flight propulsion control integration for V/STOL aircraft	Differential GPS with a sequencing receiver	REMOTE SENSING
[SAE PAPER 872330] p 522 A88-37199	p 505 A88-37406 RAKES	The effect of aircraft angular vibrations on the quality
STOVL RCS effects on propulsion system design	Riblet drag reduction at flight conditions	of remotely sensed images p 520 A88-41096
[SAE PAPER 872349] p 522 A88-37214	[AIAA PAPER 88-2554] p 494 A88-40764	REMOTELY PILOTED VEHICLES
Scale model acoustic testing of counterrotating fans	RAMJET ENGINES	Flight test experience with an RPV emergency (parachute) recovery system
[AIAA PAPER 88-2057] p 523 A88-37947	Water flow visualisation of a ramrocket combustion	[AIAA PAPER 88-2139] p 512 A88-38735
Research and technology	chamber p 549 N88-23138	REPORTS
[NASA-TM-100172] p 558 N88-22851	RANGE AND RANGE RATE TRACKING	Activities report of Lufthansa
PROPULSION SYSTEM PERFORMANCE	Results of dynamic testing of the USAF/ESMC GPS	[ISSN-0176-5086] p 476 N88-22855
Flight propulsion control integration for V/STOL	user equipment aboard the range tracking ships USNS	Aircraft accident/incident summary reports: Modena,
aircraft	Observation Island and USNS Redstone	Pennsylvania, March 17, 1986; Redwater, Texas, April 4,
[SAE PAPER 872330] p 522 A88-37199	p 503 A88-37385	1986
NASA supersonic STOVL propulsion technology	RANGE FINDERS	[PB88-910403] p 502 N88-22878
program	Analysis of a range estimator which uses MLS angle	RESEARCH
[SAE PAPER 872352] p 523 A88-37215	measurements	Aircraft flight dynamics research in past decade
An overview of rotorcraft propulsion research at Lewis	[NASA-CR-182896] p 507 N88-22884 <b>REACTION CONTROL</b>	reviewed p 518 N88-23031
Research Center p 524 A88-40554		RESEARCH AIRCRAFT
PROPULSIVE EFFICIENCY	STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214	Quiet Short-Haul Research Aircraft - A summary of flight
Propfan model wind tunnel aeroelastic research	REACTION KINETICS	research since 1981
results p 501 N88-23246	Development of a variational method for chemical kinetic	[SAE PAPER 872315] p 508 A88-37186
PROTECTIVE COATINGS	sensitivity analysis p 541 A88-38490	Some topics of ASKA's flight test results and its future plan
Kryptonite they are not anticorrosive coatings for jet	REAL TIME OPERATION	`
engine superalloys p 540 A88-37429	Reference trajectories from GPS measurements	[SAE PAPER 872317] p 508 A88-37188 The RSRA/X-Wing experiment - A status report
Corrosion-resistant thermal barrier coatings	p 503 A88-37386	[SAE PAPER 872371] p 479 A88-37225
p 540 A88-38315	A real-time aerodynamic analysis system for use in	The NASA Integrated Test Facility and its impact on
Modern surface protections for aircraft	flight	flight research
p 541 A88-39417 Model study of thermal stresses in gas-turbine blades	[AIAA PAPER 88-2128] p 512 A88-38728	[AIAA PAPER 88-2095] p 535 A88-38711
with protective coating p 542 N88-22989	Development of a real-time aeroperformance analysis	An airborne realtime data processing and monitoring
Development of a high-temperature resistant (700 F),	technique for the X-29A advanced technology	system for research aircraft
corrosion-preventive organic coating	demonstrator	[AIAA PAPER 88-2165] p 506 A88-38743
[AD-A191407] p 543 N88-23009	[AIAA PAPER 88-2145] p 512 A88-38738	Development of an interactive real-time graphics system
PROTOTYPES	Development of an interactive real-time graphics system	for the display of vehicle space positioning
Skunk Works prototyping	for the display of vehicle space positioning	[AIAA PAPER 88-2167] p 536 A88-38744
[AlAA PAPER 88-2094] p 473 A88-38710	[AIAA PAPER 88-2167] p 536 A88-38744	Study of powered-lift aircraft using jump struts
PROVING	Computer vision for flight vehicles in landing approach p 527 A88-39485	[AIAA PAPER 88-2179] p 513 A88-38749
On the validation of a code and a turbulence model	Real-time flight test data distribution and display	First flight simulator test of the head-up display for NAL
appropriate to circulation control airfoils	[NASA-TM-100424] p 538 N88-22050	QSTOL experimental aircraft (ASUKA)
[NASA-TM-100090] p 499 N88-22864	REATTACHED FLOW	[DE88-751804] p 521 N88-22896
PULSE CODE MODULATION	Separation and reattachment near theleading edge of	RESEARCH AND DEVELOPMENT
Flight test imagery - Getting more for less	a thin wing p 486 A88-39967	AlAA Flight Test Conference, 4th, San Diego, CA, May 18-20, 1988, Technical Papers p 510 A88-38701
[AIAA PAPER 88-2102] p 505 A88-38714	The effect of cross flow angle on the drag and lift	Aircraft flight flutter testing at the NASA Ames-Dryden
PULSE RADAR	coefficients of non-circular cylinder with strakes	Flight Research Facility
A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results	[AIAA PAPER 88-2599] p 493 A88-40761	[AIAA PAPER 88-2075] p 510 A88-38702
p 519 A88-39496	RECIRCULATIVE FLUID FLOW	Aerospace progress and research - The fortieth
p 313 A00-33430		
	Hot das recirculation in V/STOL	anniversary of ONERA p 557 A88-40548
	Hot gas recirculation in V/STOL [SAE PAPER 872306] p 477 A88-37178	anniversary of ONERA p 557 A88-40548 Rotorcraft research at NASA p 475 A88-40552
Q	[SAE PAPER 872306] p 477 A88-37178	
<del></del>	[SAE PAPER 872306] p 477 A88-37178 RECOVERY PARACHUTES	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554
QUALITY CONTROL	[SAE PAPER 872306] p 477 A88-37178	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis
QUALITY CONTROL Information systems for quality. Experience at the	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES  Flight test experience with an RPV emergency (parachute) recovery system  [AIAA PAPER 88-2139] p 512 A88-38735	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  R RADAR DETECTION Information properties of complex radar	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555  1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates RADAR EQUIPMENT	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  R RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  R RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  R RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil.	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555  1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  R RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  R RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448  RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555  1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research
QUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40563 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS RADIO ELECTRONICS RADIO ELECTRONICS RADIO ELECTRONICS	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage compositions	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS RAdio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel reflinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40563 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Proceedures and requirements for testing in the Langley Research Center unitary plan wind tunnel
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082] [A	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuet tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] P 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel reflinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40555 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40563 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356  RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496  RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699  RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING  Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions for a turbine fuel refinery charging San Ardo heavy crude oil p 543 N88-23011  REFUELING  Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY  Advanced capacitor development [AD-A189985] p 546 N88-22276	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-10529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-10079] p 549 N88-22446
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082] FADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS RADIO ELECTRONICS RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22468 Development of a mobile research flight test support
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446 Development of a mobile research flight test support capability
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS RAdio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuet tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446 Development of a mobile research flight test support capability [NASA-TM-100428] p 506 N88-22883
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082]  RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIA LOISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS RADIO ELECTRONICS RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment p 503 A88-37378 Features and capabilities of the DOD standard GPS	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-23220	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40568 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22468 Development of a mobile research flight test support capability [NASA-TM-100428] p 506 N88-22883
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS RADIO ELECTRONICS RAGIO-electronic equipment of aircraft: Handbook	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel reflinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-23220	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40555 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100428] p 506 N88-22883  RESEARCH MANAGEMENT Structural dynamics branch research and
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082]  P 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment p 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications p 503 A88-37379	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-2320  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES  Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100428] p 506 N88-22883  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS RADIO ELECTRONICS RAGIO-electronic equipment of aircraft: Handbook	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 546 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-23220  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40568 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100428] p 549 N88-22883 RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082]  RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIA DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment p 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-2320  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181 Reliability analysis within a Computer Aided Engineering	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch accomplishments for fiscal year 1987 [NASA-TM-100428] p 506 N88-22883  RESEARCH MANAGEMENT Structural dynamics branch accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082]  RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications p 503 A88-37378 Features and capabilities of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-23220  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES  Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 590 N88-22883  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100428] p 549 N88-22446  RESONANT FREQUENCIES Using frequency-domain methods to identify XV-15
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment p 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-2320  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NR-MP-86059-U] p 547 N88-2369	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40560 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446 Development of a mobile research flight test support capability [NASA-TM-100428] p 506 N88-22883 RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100428] p 549 N88-22446 Using frequency-domain methods to identify XV-15 aeroelastic modes
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082]  P 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment p 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 A digital P-code GPS receiver and its applications to embedded systems p 503 A88-37393	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-23220  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NIR-MP-86059-U] p 547 N88-22369 Digital avionics design and reliability analyzer	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch accomplishments for fiscal year 1987 [NASA-TM-100428] p 560 N88-22863 RESEARCH MANAGEMENT Structural dynamics branch accomplishments for fiscal year 1987 [NASA-TM-100429] p 549 N88-22446 Development of a mobile research flight test support capability [NASA-TM-100429] p 549 N88-22446 Using frequency-domain methods to identify XV-15 aeroelastic modes [SAE PAPER 87-2385] p 510 A88-37234
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082]  RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results  P 519 A88-39496 RADIO ELECTRONICS RADIO ELECTRONICS RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment  P 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications  P 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  P 503 A88-37385 A digital P-code GPS receiver and its applications to embedded systems  The Canadian Marconi Company GPS receiver - Its	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel reflinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-2320  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures [NASA-TM-100918] p 547 N88-2369 Digital avionics design and reliability analysis [NASA-CR-181641] p 554 N88-23472	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIIAA PAPER 88-2082]  RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results p 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook RUSSIAN DON AVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications  p 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone p 503 A88-37385 A digital P-code GPS receiver and its applications to embedded systems The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-23220  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p 547 N88-2369 Digital avionics design and reliability analyzer [NASA-CR-181641] p 554 N88-23472	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22466 Development of a mobile research flight test support capability [NASA-TM-100428] p 506 N88-22883  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  Development of a block Lanczos algorithm for free vibration analysis of spinning structures
CUALITY CONTROL Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274]  RADAR DETECTION Information properties of complex radar angular-coordinate estimates p 545 A88-38448 RADAR EQUIPMENT Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082]  P 505 A88-38705 RADIAL DISTRIBUTION Simulation of transonic flow in radial compressors p 480 A88-37356 RADIO ALTIMETERS A millimeter-wave low-range radar altimeter for helicopter applications - Experimental results  P 519 A88-39496 RADIO ELECTRONICS Radio-electronic equipment of aircraft: Handbook Russian book p 505 A88-37699 RADIO NAVIGATION The Canadian Marconi Company GPS receiver - Its development, test, and future p 503 A88-37394 RADIO RECEIVERS GPS phase III multi-channel user equipment  P 503 A88-37378 Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications  P 503 A88-37379 Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone  A digital P-code GPS receiver and its applications to embedded systems p 503 A88-37393 The Canadian Marconi Company GPS receiver - Its	[SAE PAPER 872306] p 477 A88-37178  RECOVERY PARACHUTES Flight test experience with an RPV emergency (parachute) recovery system [AIAA PAPER 88-2139] p 512 A88-38735  RECTANGULAR WINGS Pitch rate and Reynolds number effects on a pitching rectangular wing [AIAA PAPER 88-2577] p 491 A88-40746  REDUNDANCY Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  REDUNDANT COMPONENTS Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  REFINING Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  REFUELING Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025  RELIABILITY Advanced capacitor development [AD-A189985] p 546 N88-22276 Computerized life and reliability modelling for turboprop transmissions [NASA-TM-100918] p 551 N88-23220  RELIABILITY ANALYSIS Some aspects of the reliability analysis of aircraft structures p 544 A88-38181 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p 547 N88-2369 Digital avionics design and reliability analyzer [NLR-MP-86059-U] p 554 N88-23472  RELIABILITY ENGINEERING Information systems for quality. Experience at the	Rotorcraft research at NASA p 475 A88-40552 An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554 Rising to the challenge - Research at AATD p 475 A88-40555 1987 Technical Committee Highlights - The year in review Rotorcraft research and development p 475 A88-40558 Research and Development at Boeing Helicopters p 476 A88-40560 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561 Current rotorcraft technology advancement at MBB p 476 A88-40562 Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853  RESEARCH FACILITIES Development of an integrated set of research facilities for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712 The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research Facility [AIAA PAPER 88-2168] p 536 A88-38745 Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016 Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446  RESEARCH MANAGEMENT Structural dynamics branch research and accomplishments for fiscal year 1987 [NASA-TM-100279] p 549 N88-22446

Fluid mechanics of dynamic stall. II - Prediction of full

SHORT TAKEOFF AIRCRAFT

HORT TAKEOFF AIRCHAFT International Powered Lift Conference and Exposition, Santa Clara, CA, Dec. 7-10, 1987, Proceedings [SAE P-203] p 473 A88-37176

# **RESONANT VIBRATION**

RESONANT VIBRATION	An overview of rotorcraft propulsion research at Lewis	Fluid mechanics of dynamic stall. II - Prediction of full scale characteristics p 485 A88-39512
Numerical calculations of the natural vibrations of	Research Center p 524 A88-40554	scale characteristics p 485 A88-39512 On a least-energy hypothesis for the wake of
turbomachine blades using the finite element method p 523 A88-37543	The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556	axisymmetric bodies with turbulent separation -
REVERBERATION CHAMBERS	Research at Rensselaer Polytechnic Institute's Center	Pressure-distribution prediction
EMR (Electromagnetic Radiation) test facilities	of Excellence in rotorcraft technology	[AIAA PAPER 88-2513] p 487 A88-40705
evaluation of reverberating chamber located at RADC	p 475 A88-40557	A comparative study of differing vortex structures arising in unsteady separated flows
(Rome Air Development Center), Griffiss AFB (Air Force	1987 Technical Committee Highlights - The year in	[AIAA PAPER 88-2582] p 492 A88-40751
Base), Rome, New York (PR88-178827) p 538 N88-22048	review Rotorcraft research and development	On the prediction of highly vortical flows using an Euler
[PB88-178827] p 538 N88-22048  REYNOLDS NUMBER	p 475 A88-40558	equation model, part 2
Pitch rate and Reynolds number effects on a pitching	Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561	[AD-A190245] p 547 N88-22305
rectangular wing	Current rotorcraft technology advancement at MBB	Propfan model wind tunnel aeroelastic research results p 501 N88-23246
[AIAA PAPER 88-2577] p 491 A88-40746	p 476 A88-40562	results p 501 N88-23246 Stall flutter analysis of propfans p 552 N88-23256
REYNOLDS STRESS  Measurements in a three-dimensional turbulent	ROTORS	SERVICE LIFE
boundary-layer p 484 A88-39000	Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular	Development of a flexible and economic helicopter
Flow in out-of-plane double S-bends	planform blades at an advance ratio of 0.30	engine monitoring system [PB88-165147] p 517 N88-22887
p 484 A88-39011	NASA-TM-100543 p 497 N88-22015	[PB88-165147] p 517 N88-22887 SERVOCONTROL
The calculation of the flow through a two-dimensional faired diffuser p 485 A88-39030	Visualisation of the flow at the tip of a high speed axial	Servo-actuator control for sampled-data feedback
faired diffuser p 485 A88-39030  ROLLING	flow turbine rotor LAD-A1899281 p 546 N88-22300	disturbance rejection helicopters
Mode 2 fracture mechanics p 548 N88-22418	[AD-A189928] p 546 N88-22300 Active control and system identification of rotordynamic	[ESA-TT-1002] p 529 N88-22903
ROTARY WING AIRCRAFT	structure p 551 N88-23230	SERVOMECHANISMS Servo-actuator control for sampled-data feedback
Test stand performance of a convertible engine for	Development of aeroelastic analysis methods for	disturbance rejection helicopters
advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217	turborotors and propfans, including mistuning p 551 N88-23244	[ESA-TT-1002] p 529 N88-22903
Civil applications of high speed rotorcraft and powered	The 2-D and 3-D time marching transonic potential flow	SHARP LEADING EDGES
lift aircraft configurations	method for propfans p 501 N88-23245	Prediction of vortex lift of non-planar wings by the leading-edge suction analogy p 485 A88-39279
[SAE PAPER 872372] p 501 A88-37226	Acoustic characteristics of 1/20-scale model helicopter	leading-edge suction analogy p 485 A88-39279 SHEAR FLOW
ROTARY WINGS  Calculation of transonic rotor noise using a frequency	rotors	Velocity profile similarity for viscous flow development
domain formulation p 555 A88-38380	[NASA-CR-177355] p 557 N88-23548 RUNWAY CONDITIONS	along a longitudinally slotted wind-tunnel wall
Current rotorcraft technology advancement at MBB	Landing surface characteristics unique to V/STOL	[AIAA PAPER 88-2029] p 481 A88-37932 Measurements of turbulent flow behind a wing-body
p 476 A88-40562	aircraft	junction p 484 A88-38987
Assessment of transient testing techniques for rotor	[SAE PAPER 872310] p 530 A88-37182	SHEAR LAYERS
stability testing [AIAA PAPER 88-2401] p 546 A88-40871	The high technology test bed program - An overview	Experimental investigation of topological structures in
The use of smooth bending moment modes in helicopter	of tactical STOL airlifters [SAE PAPER 872312] p 507 A88-37183	three-dimensional separated flow p 486 A88-39970
rotor blade vibration studies p 515 A88-41222	ILS glidescope evaluation of imperfect terrain	SHEAR STRESS  Detection of large-scale organized motions in a turbulent
Tip vortices of isolated wings and helicopter rotor	p 506 A88-39135	boundary layer p 484 A88-39023
blades [AD-A191336] p 501 N88-22874	RUNWAYS Soft-ground aircraft arresting systems	SHIPS
ROTATING DISKS	[AD-A190838] p 539 N88-22912	Integrated control and display research for transition and vertical flight on the NASA V/STOL Research Aircraft
Life of gas turbine engine disks with cracks	[//E//Toodoo]	(VSRA)
p 544 A88-37549	•	
DOTATION	3	[SAE PAPER 872329] p 526 A88-37198
ROTATION  Experimental investigation of a spanwise forced mixing	S	Measurements of the time dependent velocity field
Experimental investigation of a spanwise forced mixing layer	SATELLITE COMMUNICATION	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 ROTOR AERODYNAMICS	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS Thermal state of a turbofan rotor p 545 A88-40317	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375 SATELLITE NETWORKS	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40566 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557 Current rotorcraft technology advancement at MBB p 476 A88-40562	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TEBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center  [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A68-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375 Implementation of aeronautical mobile satellite services	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK MAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions  p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40566  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  [ABA-40557]  Current rotorcraft technology advancement at MBB p 476 A88-40562  [Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40552  Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center  [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions  p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-2329	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40066	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center  [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions  p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40552  Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519 SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002]  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer 1486 A88-40421  Turbulent eddy viscosity modeling in transonic
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23230  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center  [AIAA PAPER 88-2002]  SHOCK MAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions  p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer  p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40557  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center  [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions  [AIAA PAPER 88-2592] p 493 A88-40758
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK MAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-22279  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653  SENSITIVITY  Shape sensitivity analysis of wing static characteristics [NASA-TP-2808] p 516 N88-22031	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717 Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710 Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229 Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653  SENSITIVITY  Shape sensitivity analysis of wing static aeroelastic characteristics  [NASA-TP-2808] p 516 N88-22031  SENSORS	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002]  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23220  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22833  Minimum weight design of rotorcraft blades with multiple	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377 Navigation by satellite - The next step for civil aviation p 506 A88-39375 Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice  SELF OSCILLATION Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics [NASA-TP-2808] p 516 N88-22031  SENSORS Analytical sensor redundancy assessment	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2592] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamics tructure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-22892	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653  SENSITIVITY  Shape sensitivity analysis of wing static aeroelastic characteristics  [NASA-TP-2808] p 516 N88-22031  SENSORS  Analytical sensor redundancy assessment  [NASA-CR-182892] p 521 N88-22901	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002]  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-22892  Supersonic axial-flow fan flutter p 552 N88-23255	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice  SELF OSCILLATION Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics [NASA-TP-2808] p 516 N98-22031  SENSORS Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SEPARATED FLOW Computer simulation of turbulent jets and wakes	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002]  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2592] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  La Recherche Aerospatiale, bimonthly bulletin, number
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40552  Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints  [NASA-TM-100569] p 517 N88-22892  Supersonic axial-flow fan flutter p 552 N88-23255  ROTOR BLADES (TURBOMACHINERY)	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653  SENSITIVITY  Shape sensitivity analysis of wing static aeroelastic characteristics (NASA-TP-2808) p 516 N88-22031  SENSORS  Analytical sensor redundancy assessment (NASA-TP-28082) p 521 N88-22901  SEPARATED FLOW  Computer simulation of turbulent jets and wakes p 544 A88-37661	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK MAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions  [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction  [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct  [AD-A190772] p 547 N88-22320  La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 476 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40552  Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints  [NASA-TM-100569] p 517 N88-22892  Supersonic axial-flow fan flutter p 552 N88-23255  ROTOR BLADES (TURBOMACHINERY)  Cascade lift ratios for radial and semiaxial rotating	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40519  SELF OSCILLATION Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics (INAS-TP-2808) p 516 N88-22031  SENSORS Analytical sensor redundancy assessment (INAS-CR-182892) p 521 N88-22901  SEPARATED FLOW Computer simulation of turbulent jets and wakes p 544 A88-37661	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK MAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  D 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions  [AIAA PAPER 88-2592] p 493 A88-40751  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction  [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct  [AD-A190772] p 547 N88-22320  La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June  [ESA-TT-1075] p 550 N88-23161
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-22892  Supersonic axial-flow fan flutter p 552 N88-23255  ROTOR BLADES (TURBOMACHINERY)  Cascade lift ratios for radial and semiaxial rotating cascades	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653  SENSITIVITY  Shape sensitivity analysis of wing static aeroelastic characteristics  [NASA-TP-2808] p 516 N88-22031  SENSORS  Analytical sensor redundancy assessment  [NASA-CR-182892] p 521 N88-22901  SEPARATED FLOW  Computer simulation of turbulent jets and wakes p 544 A88-37661  Separation of a supersonic boundary layer shead of the	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002]  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer interactions [AIAA PAPER 88-2592]  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592]  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2590]  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772]  La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June [ESA-TT-1075]  SHOCK WAVES
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40566 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 476 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40552  Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23220  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-23295  ROTOR BLADES (TURBOMACHINERY)  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Visualisation of the flow at the tip of a high speed axial flow turbine rotor	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40519  SELF OSCILLATION Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics (INSA-TP-2808) p 516 N88-22031  SENSORS Analytical sensor redundancy assessment (INSA-CR-182892) p 521 N88-22901  SEPARATED FLOW Computer simulation of turbulent jets and wakes p 544 A88-37661 Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697 Review of transition effects on the problem of dynamic simulation of wind tunnel tests	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK MAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  D 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions  [AIAA PAPER 88-2592] p 493 A88-40751  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction  [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct  [AD-A190772] p 547 N88-22320  La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June  [ESA-TT-1075] p 550 N88-23161
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints  [NASA-TM-100569] p 517 N88-22892  Supersonic axial-flow fan flutter p 552 N88-23255  ROTOR BLADES (TURBOMACHINERY)  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Visualisation of the flow at the tip of a high speed axial flow turbine rotor [AD-A189928] p 546 N88-22300	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics [NASA-TP-2808] p 516 N88-22031  SENSORS Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SEPARATED FLOW Computer simulation of turbulent jets and wakes p 544 A88-37661  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Review of transition effects on the problem of dynamic simulation of wind tunnel tests [AIAA PAPER 88-2004] p 532 A88-37915	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-2320  La Recherche Aerospatiale, bimonthly bullletin, number 1987-3, 238/May-June [ESA-TT-1075]  SHOCK WAVES  Calculation of external-internal flow fields for
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562 Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717 Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710 Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-2329 Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863 Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 551 N88-22992 Supersonic axial-flow fan flutter p 552 N88-23255 ROTOR BLADES (TURBOMACHINERY) Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110 Visualisation of the flow at the tip of a high speed axial flow turbine rotor [AD-A189928] p 546 N88-22300 Improvements to tilt rotor performance through passive	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS  GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE  Vehicles and aircraft on floating ice p 536 A88-40519  SEL F OSCILLATION  Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS  Numerical separation models p 480 A88-37653  SENSITIVITY  Shape sensitivity analysis of wing static aeroelastic characteristics [NASA-TP-2808] p 516 N88-22031  SENSORS  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SEPARATED FLOW  Computer simulation of turbulent jets and wakes p 544 A88-37661  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Review of transition effects on the problem of dynamic simulation of wind tunnel tests [AIAA PAPER 88-2004] p 532 A88-37915  Visualization techniques for studying high angle of attack	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002]  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-2320  La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June [ESA-TT-1075]  SHOCK WAVES  Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353  The structure of sonic underexpanded turbulent air jets in still air
Experimental investigation of a spanwise forced mixing layer  [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317  The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556  Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557  Current rotorcraft technology advancement at MBB p 476 A88-40562  Experimental and analytical aerodynamics of an advanced rotor in hover  [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23230  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multiple frequency and stress constraints  [NASA-TM-100569] p 517 N88-22892  Supersonic axial-flow fan flutter p 552 N88-23255  ROTOR BLADES (TURBOMACHINERY)  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Visualisation of the flow at the tip of a high speed axial flow turbine rotor [AD-A189928] p 546 N88-22300	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40519  SELF OSCILLATION Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics [NASA-TP-2808] p 516 N88-22031  SENSORS Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SEPARATED FLOW Computer simulation of turbulent jets and wakes p 544 A88-37661  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Review of transition effects on the problem of dynamic simulation of wind tunnel tests [AIAA PAPER 88-2004] p 532 A88-37915  Visualization techniques for studying high angle of attack separated vortical flows [AIAA PAPER 88-2025] p 544 A88-37930	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576] p 552 N88-22496  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002] p 531 A88-37913  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-3952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2592] p 493 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-22320  La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June [ESA-TT-1075] p 550 N88-23161  SHOCK WAVES  Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353  The structure of sonic underexpanded turbulent air jets in still air [AD-A190856] p 500 N88-22870
Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007  ROTOR AERODYNAMICS  Thermal state of a turbofan rotor p 545 A88-40317 The Rotorcraft Center of Excellence at the University of Maryland p 475 A88-40556 Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology  p 476 A88-40557  Current rotorcraft technology advancement at MBB  p 476 A88-40552  Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717  Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229  Active control and system identification of rotordynamic structure p 551 N88-23220  ROTOR BLADES  The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Minimum weight design of rotorcraft blades with multipe frequency and stress constraints  [NASA-TM-100569] p 517 N88-22892  Supersonic axial-flow an flutter p 552 N88-23255  ROTOR BLADES (TURBOMACHINERY)  Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110  Visualisation of the flow at the tip of a high speed axial flow turbine rotor  [AD-A189928] p 546 N88-22300  Improvements to tilt rotor performance through passive blade twist control	SATELLITE COMMUNICATION Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SATELLITE NAVIGATION SYSTEMS GPS overview -The operator's perspective p 502 A88-37377  Navigation by satellite - The next step for civil aviation p 506 A88-39375  SATELLITE NETWORKS GPS overview -The operator's perspective p 500 A88-39375  Navigation by satellite - The next step for civil aviation p 506 A88-39375  Implementation of aeronautical mobile satellite services (AMSSs) p 506 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40519  SEA ICE Vehicles and aircraft on floating ice p 536 A88-40066  SELF OSCILLATION Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219  SEMIEMPIRICAL EQUATIONS Numerical separation models p 480 A88-37653  SENSITIVITY Shape sensitivity analysis of wing static aeroelastic characteristics (NAS-TP-2808) p 516 N88-22031  SENSORS Analytical sensor redundancy assessment (NAS-CR-182892) p 521 N88-22901  SEPARATED FLOW Computer simulation of turbulent jets and wakes p 544 A88-37661 Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697 Review of transition effects on the problem of dynamic simulation of wind tunnel tests [AIAA PAPER 88-2004] p 532 A88-37915  Visualization techniques for studying high angle of attack separated vortical flows	Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155  SHOCK TESTS  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements [AD-A190576]  SHOCK TUBES  Development of the University of Texas at Arlington Aerodynamics Research Center [AIAA PAPER 88-2002]  SHOCK WAVE INTERACTION  Observation of three-dimensional 'separation' in shock wave turbulent boundary layer interactions p 486 A88-39952  Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375  Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions [AIAA PAPER 88-2592] p 493 A88-40758  Computational simulation of vortex generator effects on transonic shock/boundary layer interaction [AIAA PAPER 88-2590] p 495 A88-40771  Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct [AD-A190772] p 547 N88-2320  La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June [ESA-TT-1075]  SHOCK WAVES  Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353  The structure of sonic underexpanded turbulent air jets in still air

AlAA PAPER 88-2035 | p 481 A88-37937
On the prospects for increasing dynamic lift
p 481 A88-38167
Fluid mechanics of dynamic stall. | Unsteady flow oncepts
p 485 A88-39511

[AIAA PAPER 88-2035]

concepts

ROTORCRAFT AIRCRAFT

Rotorcraft research at NASA

Rotordynamic forces on centrifugal pump impellers p 543 A88-37108

The NASA/AHS Rotorcraft Noise Reduction Program

p 475 A88-40552

p 475 A88-40553

Effect of ground proximity on the aerodynamic	SIMULATORS	STABILITY AUGMENTATION
characteristics of the STOL aircraft	The effects of torque response and time delay on	A highly monitored AV-8B Harrier II digital flight control
[SAE PAPER 872308] p 477 A88-37180	rotorcraft vertical axis handling qualities	system
The high technology test bed program - An overview of tactical STOL airlifters	[AD-A189873] p 515 N88-22023	[SAE PAPER 872332] p 527 A88-37201
[SAE PAPER 872312] p 507 A88-37183	Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental	Stability and control augmentation system of 'ASKA'
A review of the de Havilland augmentor-wing powered-lift	determination of airplane fuel tank ullage compositions	[SAE PAPER 872334] p 527 A88-37203
concept and its future applications	[AD-A190408] p 515 N88-22025	Conceptual final paper on the preliminary design of an
[SAE PAPER 872313] p 507 A88-37184	SINGLE ENGINE AIRCRAFT	oblique flying wing SST
Performance flight testing of a single engine powered	Design, construction and flight testing the Spirit of St.	[NASA-CR-182879] p 517 N88-22891
lift aircraft	Louis	STABILITY TESTS  Assessment of transient testing techniques for rotor
[SAE PAPER 872314] p 507 A88-37185	[AIAA PAPER 88-2187] p 557 A88-38755	stability testing
Quiet Short-Haul Research Aircraft - A summary of flight	SINGLE STAGE TO ORBIT VEHICLES	[AIAA PAPER 88-2401] p 546 A88-40871
research since 1981 [SAE PAPER 872315] p 508 A88-37186	National Aero-Space Plane	STABLE OSCILLATIONS
[SAE PAPER 872315] p 508 A88-37186 Flight evaluation of an integrated control and display	[AAS PAPER 87-127] p 540 A88-41288 <b>SKIN FRICTION</b>	Oscillating airfoils: Achievements and conjectures
system for high-precision manual landing flare of	Numerical study of the skin friction on a spheroid at	[AD-A190490] p 496 N88-22008
powered-lift STOL aircraft		STAGNATION PRESSURE
[SAE PAPER 872316] p 508 A88-37187	incidence p 482 A88-38376 Time-dependent structure in wing-body junction flows	Microprocessor control of high-speed wind tunnel
Some topics of ASKA's flight test results and its future	p 484 A88-38988	stagnation pressure
plan	Riblet drag reduction at flight conditions	[AIAA PAPER 88-2062] p 535 A88-37949
[SAE PAPER 872317] p 508 A88-37188	[AIAA PAPER 88-2554] p 494 A88-40764	STANDARDS
Development of lift ejectors for STOVL combat aircraft	SKIS	Features and capabilities of the DOD standard GPS
[SAE PAPER 872324] p 522 A88-37193	Airworthiness and flight characteristics test of a ski	receivers for aircraft and seaborne applications
Thrust efficiency of powered lift systems	assembly for the UH-60A Black Hawk helicopter	p 503 A88-37379
[SAE PAPER 872327] p 522 A88-37196	[AD-A191414] p 518 N88-22895	STATE VECTORS
Propulsion/aerodynamic integration in ASTOVL combat	SLENDER BODIES	Linear state space modeling of a turbofan engine
aircraft Advanced Short Take-Off Vertical Landing ISAE PAPER 8723331 p.508 A88-37202	Numerical study of the skin friction on a spheroid at	[AD-A190110] p 524 N88-22035
Stability and control augmentation system of 'ASKA'	incidence p 482 Å88-38376 SLENDER WINGS	STATIC LOADS
[SAE PAPER 872334] p 527 A88-37203	On the prospects for increasing dynamic lift	Effect of load duration on the fatigue behaviour of
The application of circulation control pneumatic	p 481 A88-38167	graphite/epoxy laminates containing delaminations
technology to powered-lift STOL aircraft	Wing vortex-flows up into vortex breakdown - A	p 541 A88-40174
[SAE PAPER 872335] p 508 A88-37204	numerical simulation	STATIC PRESSURE
Advanced tactical transport needs and design	[AIAA PAPER 88-2518] p 487 A88-40709	The structure of sonic underexpanded turbulent air jets
implications	SLOTTED WIND TUNNELS	in still air
[SAE PAPER 872337] p 473 A88-37205	Velocity profile similarity for viscous flow development	[AD-A190856] p 500 N88-22870
Numerical simulation of compressible flow field about	along a longitudinally slotted wind-tunnel wall	STATIC STABILITY
complete ASKA aircraft configuration	[AIAA PAPER 88-2029] p 481 A88-37932	An experimental study to determine the flow and the
[SAE PAPER 872346] p 478 A88-37212	A flow-transfer device with nonmetallic diaphragms for	subsonic static and dynamic stability characteristics of
Aeroacoustics of advanced STOVL aircraft plumes	propulsion wind tunnel models	aircraft operating at high angles-of-attack
[SAE PAPER 872358] p 554 A88-37219	[AIAA PAPER 88-2048] p 534 A88-37945	p 518 N88-23129 STATISTICAL ANALYSIS
STOVL acoustic fatigue technologies [SAE PAPER 872360] p 555 A88-37221	Theoretical and experimental analysis of the slotted-wall	General aviation activity and avionics survey: 1986
[SAE PAPER 872360] p 555 A88-37221 Civil applications of high speed rotorcraft and powered	flow field in a transonic wind tunnel [SAE PAPER 871757] p 482 A88-38775	data
lift aircraft configurations	[SAE PAPER 871757] p 482 A88-38775 A panel method procedure for interference assessment	(AD-A189986) p 476 N88-22003
[SAE PAPER 872372] p 501 A88-37226	in slotted-wall wind tunnels	STATORS
The synthesis of ejector lift/vectored thrust for STOVL	[AIAA PAPER 88-2537] p 537 A88-40721	Piezoelectric pushers for active vibration control of
[SAE PAPER 872378] p 523 A88-37228	SMALL PERTURBATION FLOW	rotating machinery p 551 N88-23229
Configuration E-7 supersonic STOVL fighter/attack	Modelling the influence of small surface discontinuities	STEADY FLOW
technology program	in turbulent boundary layers	Experimental investigation on rigid hollow hemispherical
[SAE PAPER 872379] p 509 A88-37229	[AIAA PAPER 88-2594] p 546 A88-40759	parachute model in accelerating and steady flow
The F-15 STOL and maneuver technology demonstrator	SOFTWARE TOOLS	p 482 A88-38185
(S/MTD) program	Reliability analysis within a Computer Aided Engineering	Linear dynamics of supersonic inlet
[SAE PAPER 872383] p 510 A88-37232	(CAE) infrastructure	p 482 A88-38186
Wave drag and high-speed performance of supersonic	[NLR-MP-86059-U] p 547 N88-22369	Numerical simulation of wings in steady and unsteady
STOVL fighter configurations [SAE PAPER 872311] p. 479 A88-37235	A description of an automated database comparison	ground effects
[SAE PAPER 872311] p 479 A88-37235 Overview of the US/UK ASTOVL program	program [NASA-TM-100609] p 554 N88-23463	[AIAA PAPER 88-2546] p 488 A88-40728
[SAE PAPER 872365] p 473 A88-37238	[NASA-TM-100609] p 554 N88-23463 SOLID MECHANICS	Measurements of the time dependent velocity field
Flight test of the Japanese USB STOL experimental	World Congress on Computational Mechanics, 1st,	surrounding a model propeller in uniform water flow
aircraft ASKA	Austin, TX, Sept. 22-26, 1986, Proceedings	p 550 N88-23155
[AIAA PAPER 88-2180] p 513 A88-38750	p 544 A88-37351	STOPPING
Parametric study of supersonic STOVL flight	SOUND PRESSURE	Soft-ground aircraft arresting systems
characteristics	Turbulence and fluid/acoustic interaction in impinging	[AD-A190838] p 539 N88-22912
[NASA-CR-177330] p 518 N88-22893	jets	STRAIN GAGES
SIGNAL PROCESSING	[SAE PAPER 872345] p 478 A88-37211	Vehicles and aircraft on floating ice
GPS phase III multi-channel user equipment	SPACE FLIGHT	p 536 A88-40066
p 503 A88-37378 A millimeter-wave low-range radar altimeter for	Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853	STRAIN MEASUREMENT Research sensors p 548 N88-22430
helicopter applications - Experimental results	[NASA-TM-100595] p 558 N88-22853 SPACE SHUTTLES	Hesearch sensors p 548 N88-22430 STRAKES
p 519 A88-39496	An analytical method for the ditching analysis of an	
Analysis of a range estimator which uses MLS angle	airborne vehicle	The effect of cross flow angle on the drag and lift coefficients of non-circular cylinder with strakes
measurements	[AIAA PAPER 88-2521] p 514 A88-40711	[AIAA PAPER 88-2599] p 493 A88-40761
[NASA-CR-182896] p 507 N88-22884	SPACE STATIONS	Transacio Novio Otto
SIGNATURE ANALYSIS		
IR group activities at the Israel Aircraft Industries	Research and technology	Strake-denerated vortey interactions for a fighter-like
p 474 A88-40386	Research and technology [NASA-TM-100172] p 558 N88-22851	strake-generated vortex interactions for a fighter-like configuration
p 114 7100-40000	Research and technology [NASA-TM-100172] p 558 N88-22851 SPACECRAFT STRUCTURES	configuration
SIKORSKY AIRCRAFT	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural	configuration [NASA-TM-100009] p 497 N88-22010
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A'	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES Lewis Structures Technology, 1988. Volume 1: Structural Dynamics	configuration [NASA-TM-100009] p 497 N88-22010 STRAPDOWN INERTIAL GUIDANCE
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection
SIKORSKY AIRCRAFT  Development and qualification of S-76B category A' takeoff procedure featuring variable CDP and V2 speeds critical decision point	Research and technology	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit
Development and qualification of S-76B category A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS The effects of torque response and time delay on	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765
Development and qualification of S-76B category A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Rotorcraft technology development at Sikorsky Aircraft	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS The effects of torque response and time delay on rotorcraft vertical axis handling qualities	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS
Development and qualification of S-76B category A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES  Improving the reliability of silicon nitride - A case study p 540 A88-38316	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS  IR group activities at the Israel Aircraft Industries  D 474 A88-40386	configuration [NASA-TM-10009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Rotorcarlf technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES Improving the reliability of silicon nitride - A case study p 540 A88-38316  SIMULATION	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS  If group activities at the Israel Aircraft Industries p 474 A88-40386	configuration [NASA-TM-10009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Specialty three-dimensional finite element analysis
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES  Improving the reliability of silicon nitride - A case study p 540 A88-38316  SIMULATION  Experimental comparison of lightning simulation	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS IR group activities at the Israel Aircraft Industries p 474 A88-40386  SPIN DYNAMICS  Development of a block Lanczos algorithm for free	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Specialty three-dimensional finite element analysis codes p 548 N88-22393
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES  Improving the reliability of silicon nitride - A case study p 540 A88-38316  SIMULATION  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS  If group activities at the Israel Aircraft Industries p 474 A88-40386	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Specialty three-dimensional finite element analysis codes p 548 N88-22393 Minimum weight design of rotorcraft blades with multiple
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES Improving the reliability of silicon nitride - A case study p 540 A88-38316  SIMULATION  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS  IR group activities at the Israel Aircraft Industries p 474 A88-40386  SPIN DYNAMICS  Development of a block Lanczos algorithm for free vibration analysis of spinning structures p 545 A88-40117	configuration [NASA-TM-10009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Specialty three-dimensional finite element analysis codes p 548 N88-22393 Minimum weight design of rotorcraft blades with multiple frequency and stress constraints
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p. 511 A88-38727 Rotorcraft technology development at Sikorsky Aircraft p. 476 A88-40561  SILICON NITRIDES  Improving the reliability of silicon nitride - A case study p. 540 A88-38316  SIMULATION  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p. 552 N88-22496	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS I'R group activities at the Israel Aircraft Industries p 474 A88-40386  SPIN DYNAMICS  Development of a block Lanczos algorithm for free vibration analysis of spinning structures  P 545 A88-40117	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Specialty three-dimensional finite element analysis codes p 548 N88-22393 Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-22892  STRESS DISTRIBUTION
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES Improving the reliability of silicon nitride - A case study p 540 A88-38316  SIMULATION  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496  The application of linear maximum likelihood estimation	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS  IR group activities at the Israel Aircraft Industries p 474 A88-40386  SPIN DYNAMICS  Development of a block Lanczos algorithm for free vibration analysis of spinning structures p 545 A88-40117  STABILITY  Stability and control methodology for conceptual aircraft	configuration [NASA-TM-10009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Specialty three-dimensional finite element analysis codes p 548 N88-22393 Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-22892  STRESS DISTRIBUTION Addendum-dedendum type circular-arc gears for
SIKORSKY AIRCRAFT  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727 Rotorcraft technology development at Sikorsky Aircraft p 476 A88-40561  SILICON NITRIDES Improving the reliability of silicon nitride - A case study p 540 A88-38316  SIMULATION  Experimental comparison of lightning simulation techniques to CV-580 airborne lightning strike measurements  [AD-A190576] p 552 N88-22496	Research and technology [NASA-TM-100172] p 558 N88-22851  SPACECRAFT STRUCTURES  Lewis Structures Technology, 1988. Volume 1: Structural Dynamics [NASA-CP-3003-VOL-1] p 551 N88-23226  SPECIFICATIONS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023  SPECTRUM ANALYSIS I'R group activities at the Israel Aircraft Industries p 474 A88-40386  SPIN DYNAMICS  Development of a block Lanczos algorithm for free vibration analysis of spinning structures  P 545 A88-40117	configuration [NASA-TM-100009] p 497 N88-22010  STRAPDOWN INERTIAL GUIDANCE Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765  STRESS ANALYSIS Lewis Structures Technology, 1988. Volume 2: Structural Mechanics [NASA-CP-3003-VOL-2] p 548 N88-22382 Specialty three-dimensional finite element analysis codes p 548 N88-22393 Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-22892

Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis of strength-to-weight ratio p 545 A88-40280

SUPERSONIC SPEED

[AIAA PAPER 88-2143]

SYSTEMS ENGINEERING

The use of a computer model to investigate design compatibility between the QF-4 aircraft and the AQM-127A

An integrated GPS/IRS design approach

p 512 A88-38736

p 504 A88-37404

# STRUCTURAL ANALYSIS

STRUCTURAL ANALYSIS	SUPERCRITICAL AIRFOILS	SUPERSONIC SPEED Theoretical investigations, and correlative studies for
World Congress on Computational Mechanics, 1st,	On inverse airfoil design	NLF, HLFC, and LFC swept wings at subsonic, transonic
Austin, TX, Sept. 22-26, 1986, Proceedings	[AIAA PAPER 88-2573] p 495 A88-41048	and supersonic speeds
p 544 A88-3/351	Investigation of side-wall effects in wind tunnel with	[SAE PAPER 871861] p 483 A88-38950
Research at Rensselaer Polytechnic Institute's Center	supercritical airfoil testing p 498 N88-22241	The structure of sonic underexpanded turbulent air jets
of Excellence in rotorcraft technology	SUPERSONIC AIRCRAFT	in still air
p 475 A88-40557	STOVL acoustic fatigue technologies	[AD-A190856] p 500 N88-22870
The composite blade structural analyzer (COBSTRAN)	[SAE PAPER 872360] p 555 A88-37221	SUPERSONIC TRANSPORTS
p 525 N88-22390	Configuration E-7 supersonic STOVL fighter/attack	Conceptual final paper on the preliminary design of an
Computational structural mechanics for engine	technology program	oblique flying wing SST
structures p 525 N88-22399	[SAE PAPER 872379] p 509 A88-37229	[NASA-CR-182879] p 517 N88-22891
Structural analyses of engine wall cooling concepts and	Applying vectored thrust V/STOL experience in	SUPERSONIC WIND TUNNELS
materials p 542 N88-22405	supersonic designs	Unexpected/expected results from the Langley 20-Inch
Improvements to till rotor performance through passive	[SAE PAPER 872381] p 509 A88-37230	Supersonic Wind Tunnel during initial checkout
blade twist control	A supersonic design with V/STOL capability	[AIAA PAPER 88-1999] p 531 A88-37911
[NASA-TM-100583] p 548 N88-22434	[SAE PAPER 872382] p 509 A88-37231	Development of the University of Texas at Arlington
Research and technology	Wave drag and high-speed performance of supersonic	Aerodynamics Research Center
NASA-TM-100172] p 558 N88-22851	STOVL fighter configurations	[AIAA PAPER 88-2002] p 531 A88-37913
Vibration and flutter analysis of the SR-7L large-scale	[SAE PAPER 872311] p 479 A88-37235	Microprocessor control of high-speed wind tunnel
propriate	Aerodynamics of supersonic shapes Russian book	stagnation pressure
STRUCTURAL DESIGN  Design studies of primary aircraft structures in ARALL	p 486 A88-40311	[AIAA PAPER 88-2062] p 535 A88-37949
	Propulsion and airframe aerodynamic interactions of	Numerical and experimental investigation of multiple
laminates   LR-520   p 517 N88-22888	supersonic V/STOL configurations. Volume 1: Wind tunnel	shock wave/turbulent boundary layer interactions in a
STRUCTURAL MEMBERS	test pressure data report	rectangular duct
A study of damage tolerance in curved composite	[NASA-CR-177343-VOL-1] p 500 N88-22866	[AD-A190772] p 547 N88-22320
panels	Propulsion and airframe aerodynamic interactions of	SURFACE FINISHING
[AD-A190617] p 541 N88-22092	supersonic V/STOL configurations. Volume 2: Wind tunnel	Modern surface protections for aircraft p 541 A88-39417
STRUCTURAL STABILITY	test force and moment data report	SURFACE ROUGHNESS EFFECTS
Numerical calculations of the natural vibrations of	[NASA-CR-177343-VOL-2] p 500 N88-22867	ILS glidescope evaluation of imperfect terrain
turbomachine blades using the finite element method	Propulsion and airframe aerodynamic interactions of	p 506 A88-39135
p 523 A88-37543	supersonic V/STOL configurations. Volume 4: Summary	Modelling the influence of small surface discontinuities
Osprey's VSLED - Rewriting the maintenance manual	[NASA-CR-177343-VOL-4] p 500 N88-22868	in turbulent boundary layers
vibration, structural life, and engine diagnostics	Parametric study of supersonic STOVL flight	[AIAA PAPER 88-2594] p 546 A88-40759
system p 474 A88-39325	characteristics	SURFACE TEMPERATURE
STRUCTURAL VIBRATION	[NASA-CR-177330] p 518 N88-22893	Landing surface characteristics unique to V/STOL
Osprey's VSLED - Rewriting the maintenance manual	SUPERSONIC BOUNDARY LAYERS	aircraft
vibration, structural life, and engine diagnostics	Separation of a supersonic boundary layer ahead of the	[SAE PAPER 872310] p 530 A88-37182
system p 474 A88-39325	base of a body p 480 A88-37697	Heating requirements and nonadiabatic surface effects
Mechanisms of active control for noise inside a vibrating	On hypersonic transition testing and prediction	for a model in the NTF cryogenic wind tunnel
cylinder p 555 A88-39722	[AIAA PAPER 88-2007] p 532 A88-37916	[AIAA PAPER 88-2044] p 534 A88-37944
The use of smooth bending moment modes in helicopter rotor blade vibration studies p 515 A88-41222	Detection of large-scale organized motions in a turbulent	Research sensors p 548 N88-22430
	boundary layer p 484 A88-39023	SURVEILLANCE RADAR
Lewis Structures Technology, 1988. Volume 1: Structural	Experimental study of a supersonic turbulent boundary	Taxiway safety using mode S SSR
Dynamics  NASA-CP-3003-VOL-1  p 551 N88-23226	layer using a laser Doppler anemometer	p 519 A88-39495
Piezoelectric pushers for active vibration control of	p 485 A88-39623	SWEPT FORWARD WINGS
	SUPERSONIC COMBUSTION	Effects of maneuver dynamics on drag polars of the
Totaling maximum,	Turbulent reacting flows and supersonic combustion	X-29A forward-swept-wing aircraft with automatic wing
STRUTS	[AD-A189690] p 541 N88-22115	camber control
Study of powered-lift aircraft using jump struts	SUPERSONIC COMBUSTION RAMJET ENGINES	[AIAA PAPER 88-2144] p 527 A88-38737
(7.00.01.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.	Numerical and experimental investigation of multiple	SWEPT WINGS
SUBCRITICAL FLOW	shock wave/turbulent boundary layer interactions in a	On the prospects for increasing dynamic lift
On inverse airfoil design	rectangular duct	p 481 A88-38167
17	[AD-A190772] p 547 N88-22320	Theoretical investigations, and correlative studies for
SUBSONIC AIRCRAFT	SUPERSONIC FLOW	NLF, HLFC, and LFC swept wings at subsonic, transonic
Impact pressure error on the EC-18B subsonic aircraft I AIAA PAPER 88-2177   p 513 A88-38748	NASA supersonic STOVL propulsion technology	and supersonic speeds
(/	program	[SAE PAPER 871861] p 483 A88-38950
SUBSONIC FLOW	[SAE PAPER 872352] p 523 A88-37215	Measurements in a three-dimensional turbulent
Numerical simulation of a subsonic jet in a crossflow ISAE PAPER 8723431 p 478 A88-37209	An isentropic compression heated Ludwieg tube	boundary-layer p 484 A88-39000
	transient wind tunnel	Boundary-layer and wake measurements on a swept,
Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665	[AIAA PAPER 88-2019] p 533 A88-37926	circulation-control wing
	Adaptation of flexible wind tunnel walls for supersonic	[NASA-TM-89426] p 497 N88-22013
Experimental measurements on an oscillating 70-degree	flows	Theoretical investigation of secondary instability of
delta wing in subsonic flow LAIAA PAPER 88-2576 l p 491 A88-40745	[AIAA PAPER 88-2039] p 534 A88-37941	three-dimensional boundary-layer flows with application to
(	Heat flux on the surface of a wedge in Mach reflection	the DFVLR-F5 model wing
Development of an airfoil of high lift/drag ratio and low	and regular reflection of shock waves	[DFVLR-FB-87-44] p 547 N88-22330
moment coefficient for subsonic flow p 495 A88-40972	p 486 A88-40375	Nonlinear wave interactions in swept wing flows
•	Experimental and theoretical study of the effects of wing	[NASA-CR-4142] p 550 N88-23160
SUBSONIC SPEED	geometry on a supersonic multibody configuration	SWEPTBACK WINGS
Boundary-layer stability analysis of NLF and LFC	[AIAA PAPER 88-2510] p 494 A88-40766	Prediction of vortex lift of non-planar wings by the
experimental data at subsonic and transonic speeds [SAE PAPER 871859] p 483 A88-38925	Numerical and experimental investigation of multiple	leading-edge suction analogy p 485 A88-39279
	shock wave/turbulent boundary layer interactions in a	SYMMETRICAL BODIES
Theoretical investigations, and correlative studies for NLF, HLFC, and LFC swept wings at subsonic, transonic	rectangular duct	Aerodynamics of supersonic shapes Russian book
	[AD-A190772] p 547 N88-22320	p 486 A88-40311
and supersonic speeds [SAE PAPER 871861] p 483 A88-38950	Analysis for high compressible supersonic flow in	SYSTEM FAILURES
(One in Enterin	converging nozzle	Aircraft accident/incident summary reports: Modena,
SUBSONIC WIND TUNNELS  Aerodynamic flow quality and acoustic characteristics	[IPPJ-860] p 500 N88-22869	Pennsylvania, March 17, 1986; Redwater, Texas, April 4,
of the 40- by 80-foot test section circuit of the National	An integral equation for the linearized supersonic flow	1986
Full-Scale Aerodynamic Complex	over a wing	[PB88-910403] p 502 N88-22878
[SAE PAPER 872328] p 530 A88-37197	[AD-A191408] p 501 N88-22875	Expanded envelope concepts for aircraft
Visualization techniques for studying high angle of attack	SUPERSONIC INLETS  Linear dynamics of supersonic inlet	control-element failure detection and identification
separated vortical flows	p 482 A88-38186	[NASA-CR-181664] p 507 N88-22886
[AIAA PAPER 88-2025] p 544 A88-37930		
	·	SYSTEM IDENTIFICATION
1	SUPERSONIC JET FLOW	Active control and system identification of rotordynamic
SUCTION	SUPERSONIC JET FLOW Supersonic jet plume interaction with a flat plate	Active control and system identification of rotordynamic structure p 551 N88-23230
1	SUPERSONIC JET FLOW Supersonic jet plume interaction with a flat plate	Active control and system identification of rotordynamic

Test Program

AQM-127A

[AIAA PAPER 88-2143]

AlAA PAPER 88-2121] p 511 A88-38722
The use of a computer model to investigate design compatibility between the QF-4 aircraft and the

p 511 A88-38722

p 512 A88-38736

conditions

[AD-A187479]

Flow quality of NAL two-dimensional transonic wind

tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911

p 495 N88-22004

A millimeter-wave low-range radar altimeter for	Study on mode for a magnetic conservation	THE DATE OF LATER DECIMAL
helicopter applications - Experimental results	Study on needs for a magnetic suspension system operating with a transonic wind tunnel	THERMOPLASTIC RESINS
p 519 A88-39496	[AIAA PAPER 88-2014] p 533 A88-37922	A study of failure characteristics in thermoplastic composite material
Designs of profiles for cascades	Skunk Works prototyping	
[NASA-TT-20161] p 547 N88-22326	[AIAA PAPER 88-2094] p 473 A88-38710	[AD-A190613] p 542 N88-22940 THIN WINGS
Reliability analysis within a Computer Aided Engineering	Optical technology application in aircraft	
(CAE) infrastructure	p 474 A88-40532	Separation and reattachment near theleading edge of a thin wing p 486 A88-39967
[NLR-MP-86059-U] p 547 N88-22369	Aircraft without airports - Changing the way men fly	a thin wing p 486 A88-39967 THREAT EVALUATION
Basic design studies for the realization of liquid crystal	tilt-rotor vehicles technology p 476 A88-40559	Investigations of test methodology for the stress loading
display systems in aircraft	TELEVISION CAMERAS	facility
[VA-87-001] p 521 N88-22900	Developing a wide field of view HMD for simulators	[PB88-166095] p 538 N88-22049
SYSTEMS INTEGRATION	Helmet Mounted Display p 520 A88-41367	THREE DIMENSIONAL BOUNDARY LAYER
GPS phase III multi-channel user equipment	TEMPERATURE CONTROL	Measurements in a three-dimensional turbulent
p 503 A88-37378	Advanced capacitor development	boundary-layer p 484 A88-39000
Features and capabilities of the DOD standard GPS	[AD-A189985] p 546 N88-22276	Fourth-order accurate calculations of the 3-D
receivers for aircraft and seaborne applications	TENSILE TESTS	compressible boundary layers on aerospace
p 503 A88-37379	A study of failure characteristics in thermoplastic	configurations
	composite material	[AIAA PAPER 88-2522] p 487 A88-40712
Reference trajectories from GPS measurements	[AD-A190613] p 542 N88-22940	Theoretical investigation of secondary instability of
p 503 A88-37386	TEST FACILITIES	three-dimensional boundary-layer flows with application to
Integration of GPS receivers into existing inertial	A plan for coupling wind tunnel testing with CFD	the DFVLR-F5 model wing
navigation systems p 504 A88-37399	techniques	[DFVLR-FB-87-44] p 547 N88-22330
A fully integrated GPS/Doppler/inertial navigation	[AIAA PAPER 88-1996] p 531 A88-37909	THREE DIMENSIONAL FLOW
system p 504 A88-37400	Aircraft flight flutter testing at the NASA Ames-Dryden	The Basic Aerodynamics Research Tunnel - A facility
GPS integration with low-cost inertial navigation unit	Flight Research Facility	dedicated to code validation
p 504 A88-37402	[AIAA PAPER 88-2075] p 510 A88-38702	[AIAA PAPER 88-1997] p 531 A88-37910
An integrated GPS/IRS design approach	The NASA Integrated Test Facility and its impact on	Adaptive wall research with two- and three-dimensional
p 504 A88-37404	flight research	models in low speed and transonic tunnels
Integration of differential GPS with INS for precise	[AIAA PAPER 88-2095] p 535 A88-38711	[AIAA PAPER 88-2037] p 533 A88-37939
position, attitude and azimuth determination	Rotorcraft research at NASA p 475 A88-40552	Two-dimensional and three-dimensional adaptation at
p 504 A88-37405	Procedures and requirements for testing in the Langley	the T2 transonic wind tunnel of Onera/Cert
Keys to a successful flight test	Research Center unitary plan wind tunnel	[AIAA PAPER 88-2038] p 534 A88-37940
[AIAA PAPER 88-2174] p 519 A88-38766	[NASA-TM-100529] p 497 N88-22016	The use of 2-D adaptive wall test sections for 3-D
Reflections on the integration of avionics equipment	Small engine components test facility turbine testing	flows
	cell	[AIAA PAPER 88-2041] p 534 A88-37943
p 519 A88-40517	[NASA-TM-100887] p 525 N88-22037	Analytical study of friction and heat transfer in the vicinity
Rising to the challenge - Research at AATD	Investigation of aeroacoustic mechanisms by remote	of a three-dimensional critical point at low and moderate
p 475 A88-40555	thermal imaging	Reynolds numbers p 483 A88-38847
SYSTEMS SIMULATION	[DE88-002612] p 538 N88-22046	LDV measurements on impinging twin-jet fountain flows
A flow-transfer device with nonmetallic diaphragms for	EMR (Electromagnetic Radiation) test facilities	with a simulated fuselage undersurface
propulsion wind tunnel models	evaluation of reverberating chamber located at RADC	p 484 A88-38986
[AIAA PAPER 88-2048] p 534 A88-37945	(Rome Air Development Center), Griffiss AFB (Air Force	Observation of three-dimensional 'separation' in shock
Mach number corrections for a two-foot propeller rig	Base), Rome, New York	wave turbulent boundary layer interactions
in solid and slotted test sections	[PB88-178827] p 538 N88-22048	p 486 A88-39952
[AIAA PAPER 88-2056] p 534 A88-37946	Investigations of test methodology for the stress loading	Experimental investigation of topological structures in
Scale model acoustic testing of counterrotating fans	facility	three-dimensional separated flow p 486 A88-39970
[AIAA PAPER 88-2057] p 523 A88-37947	[PB88-166095] p 538 N88-22049	Three-dimensional unsteady transonic viscous-inviscid
	Airworthiness and flight characteristics test of a ski	interaction using the Euler and boundary-layer equations
Ŧ	assembly for the UH-60A Black Hawk helicopter	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747
Т	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p 518 N88-22895	[Alaa Paper 88-2578] p 491 A88-40747
T.22 AIRCRAET	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p 518 N88-22895 TEST RANGES	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the
T-33 AIRCRAFT	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p 518 N88-22895 TEST RANGES Using GPS to enhance the DT&E ranges	[Alaa Paper 88-2578] p 491 A88-40747
T-33 aircraft demonstration of GPS aided inertial	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p.518 N88-22895  TEST RANGES Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p.536 A88-38713	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p.518 N88-22895  TEST RANGES Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p.536 A88-38713 Flight testing at the West Coast Offshore Operating	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p.518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p.536 A88-38713  Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p.536 A88-38740	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713  Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740  Development of a mobile research flight test support	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895 TEST RANGES Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713  Flight testing at the West Coast Offshore Operating  Area   AIAA PAPER 88-2150   p 536 A88-38740   Development of a mobile research flight test support capability	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF	assembly for the UH-60A Black Hawk helicopter [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 A88-38713  Flight testing at the West Coast Offshore Operating Area [AIAA PAPER 88-2150] p 536 A88-38740  Development of a mobile research flight test support capability [AIAA PAPER 88-2087] p 536 A88-38761	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A'	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   p 518 N88-22895   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895  TEST RANGES Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713  Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740  Development of a mobile research flight test support capability  AIAA PAPER 88-2087  p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point	assembly for the UH-60A Black Hawk helicopter  [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges  [AIAA PAPER 88-2098] p 536 A88-38713  Flight testing at the West Coast Offshore Operating  Area  [AIAA PAPER 88-2150] p 536 A88-38740  Development of a mobile research flight test support  capability  [AIAA PAPER 88-2087] p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A  engine at Warfield ANG, Baltimore, Maryland	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   p 518 N88-22895   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Measurement of multipath propagation of	assembly for the UH-60A Black Hawk helicopter    AD-A191414   p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges    AIAA PAPER 88-2098   p 536 A88-38713   Flight testing at the West Coast Offshore Operating  Area    AIAA PAPER 88-2150   p 536 A88-38740   Development of a mobile research flight test support  capability    AIAA PAPER 88-2087   p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966   p 556 N88-22702  THERMAL CONTROL COATINGS	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments	assembly for the UH-60A Black Hawk helicopter  [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges  [AIAA PAPER 88-2098] p 536 A88-38713  Flight testing at the West Coast Offshore Operating  Area  [AIAA PAPER 88-2150] p 536 A88-38740  Development of a mobile research flight test support  capability  [AIAA PAPER 88-2087] p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A  engine at Warfield ANG, Baltimore, Maryland  [AD-A189966] p 556 N88-22702  THERMAL CONTROL COATINGS  Kryptonite they are not anticorrosive coatings for jet	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] Accuracy versus convergence rates for a three
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813 Advanced turboprop aircraft flyover noise: Annoyance	assembly for the UH-60A Black Hawk helicopter   AD-A191414  p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating  Area    AIAA PAPER 88-2150  p 536 A88-38740    Development of a mobile research flight test support  Capability    AIAA PAPER 88-2087  p 536 A88-38761  TF-34 ENGINE    Noise assessment of unsuppressed TF-34-GE-100A   engine at Warfield ANG, Baltimore, Maryland  AD-A189966  p 556 N88-22702  THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] Accuracy versus convergence rates for a three dimensional multistage Euler code
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal	assembly for the UH-60A Black Hawk helicopter  [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges  [AIAA PAPER 88-2098] p 536 A88-38713  Flight testing at the West Coast Offshore Operating Area  [AIAA PAPER 88-2150] p 536 A88-38740  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  [AD-A189966] p 556 N88-22702  THERMAL CONTROL COATINGS  Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429  Corrosion-resistant thermal barrier coatings	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results	assembly for the UH-60A Black Hawk helicopter  [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges  [AIAA PAPER 88-2098] p 536 A88-38713  Flight testing at the West Coast Offshore Operating Area  [AIAA PAPER 88-2150] p 536 A88-38740  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  [AD-A189966] p 556 N88-22702  THERMAL CONTROL COATINGS  Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429  Corrosion-resistant thermal barrier coatings	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429   Corrosion-resistant thermal barrier coatings	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] THRUST AUGMENTATION Advances in ejector thrust augmentation
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS	assembly for the UH-60A Black Hawk helicopter  [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges  [AIAA PAPER 88-2098] p 536 A88-38713  Flight testing at the West Coast Offshore Operating Area  [AIAA PAPER 88-2150] p 536 A88-38740  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  [AD-A189966] p 556 N88-22702  THERMAL CONTROL COATINGS  Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429  Corrosion-resistant thermal barrier coatings  Evaluation of ceramic thermal barrier coatings for gas turbine engine components  [ETN-88-91947] p 543 N88-22998	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Ding GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740 Development of a mobile research flight test support capability  AIAA PAPER 88-2087  p 536 A88-38761	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 552 A88-37191 Estimation of thrust augmentor performance in V/STOL
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813 Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Ding GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713 Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740 Development of a mobile research flight test support capability  AIAA PAPER 88-2087  p 536 A88-38761	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING	assembly for the UH-60A Black Hawk helicopter  [AD-A191414] p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges  [AIAA PAPER 88-2098] p 536 A88-38713  Flight testing at the West Coast Offshore Operating Area  [AIAA PAPER 88-2150] p 536 A88-38740  Development of a mobile research flight test support capability  [AIAA PAPER 88-2087] p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  [AD-A189966] p 556 N88-22702  THERMAL CONTROL COATINGS  Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429  Corrosion-resistant thermal barrier coatings  Evaluation of ceramic thermal barrier coatings for gas turbine engine components  [ETN-88-91947] p 543 N88-22998	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts  [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429   Corrosion-resistant thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-22998   THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727 Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced furboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUMS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered	assembly for the UH-60A Black Hawk helicopter   AD-A191414  p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area   AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761  TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702  THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429   Corrosion-resistant thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-2298  THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-3815   Evaluation of ceramic thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-22998   THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612  p 538 N88-22046	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts  [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability  AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-38315   Evaluation of ceramic thermal barrier coatings for gas turbine engine components   ETN-89-91947  p 543 N88-22998   THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612  p 538 N88-22046   THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced furboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863	assembly for the UH-60A Black Hawk helicopter   AD-A191414  p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area   AIAA PAPER 88-2150  p 536 A88-38740    Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761  TF-34 ENGINE    Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702  THERMAL CONTROL COATINGS    Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429    Corrosion-resistant thermal barrier coatings   p 540 A88-38315    Evaluation of ceramic thermal barrier coatings for gas turbine engine components    ETN-88-91947  p 543 N88-22998  THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging    DEB8-002612  p 538 N88-22046  THERMAL PROTECTION    Aerothermal tests of quilted dome models on a flat plate	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil.	assembly for the UH-60A Black Hawk helicopter    AD-A191414   p 518 N88-22895  TEST RAMGES  Using GPS to enhance the DT&E ranges    AIAA PAPER 88-2098   p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area    AIAA PAPER 88-2150   p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087   p 536 A88-38761  TF-34 ENGINE  Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966   p 556 N88-22702  THERMAL CONTROL COATINGS  Kryptonite they are not anticorrosive coatings for jet engine superalloys corrosion-resistant thermal barrier coatings   D 540 A88-38315   Evaluation of ceramic thermal barrier coatings for gas turbine engine components   ETN-88-91947   p 543 N88-22998  THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612   p 538 N88-22046  THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187]
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts  [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a	assembly for the UH-60A Black Hawk helicopter   AD-A191414  p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area   AIAA PAPER 88-2150  p 536 A88-38740    Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761    TF-34 ENGINE    Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702    THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-3815    Evaluation of ceramic thermal barrier coatings for gas turbine engine components    ETN-88-91947  p 543 N88-22998    THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612   p 538 N88-22046    THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   NASA-TP-2804  p 547 N88-23255	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts  [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895  ASSEMBLY N88-22895   P 518 N88-22895  ASSEMBLY N88-2098  p 536 A88-38713    ASSEMBLY N88-2098  p 536 A88-38713    ASSEMBLY N88-2098  p 536 A88-38740    ASSEMBLY N88-2150  p 536 A88-38740    ASSEMBLY N88-2150  p 536 A88-38740    ASSEMBLY N88-2150  p 536 A88-38761    ASSEMBLY N88-3876  p 536 A88-38761    ASSEMBLY N88-22702    ASSEMBLY N88-22702    ASSEMBLY N88-22702    ASSEMBLY N88-37429    ASSEMBLY N88-37429    ASSEMBLY N88-38315    AS	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-4181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AIAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011	assembly for the UH-60A Black Hawk helicopter   AD-A191414  p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area   AIAA PAPER 88-2150  p 536 A88-38740    Development of a mobile research flight test support capability   AIAA PAPER 88-2150  p 536 A88-38761    TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702    THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-3815    Evaluation of ceramic thermal barrier coatings for gas turbine engine components    ETN-88-91947  p 543 N88-22998    THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612  p 538 N88-22046    THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   INASA-TP-2804  P 547 N88-22325    THERMAL STABILITY   Elevated-temperature Al alloys for aircraft structure	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 526 A88-37200
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts  [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil (AD-A190120)  TARRET RECOGNITION	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-3815   Evaluation of ceramic thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-22998   THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612  p 538 N88-22046   THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   [NASA-TP-2804  p 547 N88-22325   THERMAL STABILITY   Elevated-temperature Al alloys for aircraft structure p 541 A88-40486	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts  [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Tar SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2: phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification	assembly for the UH-60A Black Hawk helicopter   AD-A191414  p 518 N88-22895  TEST RANGES  Using GPS to enhance the DT&E ranges   AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area   AIAA PAPER 88-2150  p 536 A88-38740    Development of a mobile research flight test support capability   AIAA PAPER 88-2150  p 536 A88-38761    Development of a mobile research flight test support capability    AIAA PAPER 88-2087  p 536 A88-38761    TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland    AD-189966  p 556 N88-22702    THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429    Corrosion-resistant thermal barrier coatings for gas turbine engine components    Evaluation of ceramic thermal barrier coatings for gas turbine engine components    EVALUATION OF COATINGS   P 540 A88-38315    Evaluation of ceramic thermal barrier coatings for gas turbine engine components    EVALUATION OF COATINGS   P 540 A88-38315    EVALUATION OF COATINGS   P 541 N88-22998    THERMAL MAPPING   P 543 N88-22998    THERMAL MAPPING   P 546 N88-22046    THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   NASA-TP-2804   P 547 N88-22325    THERMAL STABILITY   Elevated-temperature Al alloys for aircraft structure	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control (SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872331] p 526 A88-37200
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter	assembly for the UH-60A Black Hawk helicopter   AD-A191414   p 518 N88-22895    TEST RANGES	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil (AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698	assembly for the UH-60A Black Hawk helicopter   AD-A191414   p 518 N88-22895    TEST RANGES	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control (SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST  [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point  [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results  [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts  [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15  [NASA-TM-100544] p 499 N88-22863  Tar SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TARECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 EMGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-3815   Evaluation of ceramic thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-22998   THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612  p 538 N88-22046   THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   [NASA-TP-2804  p 547 N88-22325   THERMAL STABILITY   Elevated-temperature Al alloys for aircraft structure p 541 A88-40486   THERMAL STRESSES   Factors affecting the temperature state of the blading of high-temperature combustor liner tests in structural component response test facility p 525 N88-22383	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-4181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL superience in supersonic designs [SAE PAPER 872381] p 523 A88-37230
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil (AD-A190120) p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895  TEST RANGES	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872323] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-768 category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2. phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil (AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698  TAXING  Taxiway safety using mode S SSR	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability  AIAA PAPER 88-2087  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland    AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429     Corrosion-resistant thermal barrier coatings   Corrosion-resistant thermal barrier coatings   p 540 A88-38315     Evaluation of ceramic thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-22998     THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DEB8-002612  p 538 N88-22046     THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   NASA-TP-2804  p 547 N88-2325     THERMAL STABILITY   Elevated-temperature Al alloys for aircraft structure   p 541 A88-40486     THERMAL STRESSES   Factors affecting the temperature state of the blading of high-temperature combustor liner tests in structural component response test facility   p 528 N88-22383     N88-22383	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control (SAE PAPER 872331] p 523 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872381] p 523 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872381] p 509 A88-37230 Application of Navier-Stokes analysis to predict the internal performance of thrust vectoring two-dimensional
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698  TAXING  Taxiway safety using mode S SSR	assembly for the UH-60A Black Hawk helicopter   AD-A191414   p 518 N88-22895    TEST RANGES	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872323] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL  The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 523 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872331] p 523 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872338] p 520 A88-37200 Application of Navier-Stokes analysis to predict the internal performance of thrust vectoring two-dimensional convergent-divergent nozzles
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced furboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil (AD-A190120) p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698  TAXING  Taxiway safety using mode S SSR  p 519 A88-39495	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2087  p 536 A88-38761   TF-34 EMGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland  AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429   Corrosion-resistant thermal barrier coatings for gas turbine engine components   EVALUATION OF COATINGS   EVALUATION OF COATINGS	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-2319 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL (SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL (SAE PAPER 872331] p 528 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL (SAE PAPER 872331] p 520 A88-37200 Application of Navier-Stokes analysis to predict the internal performance of thrust vectoring two-dimensional convergent-divergent nozzles [AlAA PAPER 88-2586] p 493 A88-40755
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2. phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil (AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698  TAXING  Taxiway safety using mode S SSR  p 519 A88-39495  TECHNOLOGICAL FORECASTING  Aerospace equipment - Evolution and future problems p 474 A88-40522	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2150  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429   Corrosion-resistant thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-22998   THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612  p 538 N88-22046   THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   NASA-TP-2804  p 547 N88-22325   THERMAL STABILITY   Elevated-temperature Al alloys for aircraft structure p 541 A88-40486   THERMAL STRESSES   Factors affecting the temperature state of the blading of high-temperature combustor liner tests in structural component response test facility p 525 N88-22393   Specialty three-dimensional finite element analysis codes p 548 N88-22394   Structural analyses of engine wall cooling concepts and	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft (SAE PAPER 872324) p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered plantorm blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698  TAXING  Taxiway safety using mode S SSR  p 519 A88-39495  TECHNOLOGICAL FORECASTING  Aerospace equipment - Evolution and future problems p 474 A88-40522	assembly for the UH-60A Black Hawk helicopter   AD-A191414   p 518 N88-22895    TEST RANGES	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows [NASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control [SAE PAPER 872331] p 526 A88-37200 The synthesis of ejector lift/vectored thrust for STOVL experience in supersonic designs [SAE PAPER 872381] p 529 A88-37230 Application of Navier-Stokes analysis to predict the internal performance of thrust vectoring two-dimensional convergent-divergent nozzles [AlAA PAPER 88-2586] p 493 A88-40755 X-31 - Through the grape barrier highly maneuverable fighter aircraft
T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403  TAILLESS AIRCRAFT  Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891  TAKEOFF  Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds critical decision point [AIAA PAPER 88-2127] p 511 A88-38727  Measurement of multipath propagation of electromagnetic waves in actual airport environments p 506 A88-39813  Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results [NASA-TM-100612] p 557 N88-23547  TAKEOFF RUNS  Study of powered-lift aircraft using jump struts [AIAA PAPER 88-2179] p 513 A88-38749  TAPERING  Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15 [NASA-TM-100544] p 499 N88-22863  TAR SANDS  Turbine fuels from tar sands bitumen and heavy oil. Volume 2. phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil (AD-A190120] p 543 N88-23011  TARGET RECOGNITION  Method and device for the detection and identification of a helicopter [NASA-TT-20251] p 556 N88-22698  TAXING  Taxiway safety using mode S SSR  p 519 A88-39495  TECHNOLOGICAL FORECASTING  Aerospace equipment - Evolution and future problems p 474 A88-40522	assembly for the UH-60A Black Hawk helicopter  AD-A191414  p 518 N88-22895   TEST RANGES   Using GPS to enhance the DT&E ranges  AIAA PAPER 88-2098  p 536 A88-38713   Flight testing at the West Coast Offshore Operating Area  AIAA PAPER 88-2150  p 536 A88-38740   Development of a mobile research flight test support capability   AIAA PAPER 88-2150  p 536 A88-38761   TF-34 ENGINE   Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland   AD-A189966  p 556 N88-22702   THERMAL CONTROL COATINGS   Kryptonite they are not anticorrosive coatings for jet engine superalloys p 540 A88-37429   Corrosion-resistant thermal barrier coatings for gas turbine engine components   ETN-88-91947  p 543 N88-22998   THERMAL MAPPING   Investigation of aeroacoustic mechanisms by remote thermal imaging   DE88-002612  p 538 N88-22046   THERMAL PROTECTION   Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5   NASA-TP-2804  p 547 N88-22325   THERMAL STABILITY   Elevated-temperature Al alloys for aircraft structure p 541 A88-40486   THERMAL STRESSES   Factors affecting the temperature state of the blading of high-temperature combustor liner tests in structural component response test facility p 525 N88-22393   Specialty three-dimensional finite element analysis codes p 548 N88-22394   Structural analyses of engine wall cooling concepts and	[AlAA PAPER 88-2578] p 491 A88-40747 Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AlAA PAPER 88-2516] p 493 A88-40762 Navier-Stokes computation of flow around a round-edged double-delta wing [AlAA PAPER 88-2560] p 494 A88-40767 Experimental investigation of a spanwise forced mixing layer [AD-A190136] p 496 N88-22007 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Nonlinear wave interactions in swept wing flows INASA-CR-4142] p 550 N88-23160 Accuracy versus convergence rates for a three dimensional multistage Euler code [NASA-CR-181665] p 554 N88-23519 THRUST AUGMENTATION Advances in ejector thrust augmentation [SAE PAPER 872322] p 522 A88-37191 Estimation of thrust augmentor performance in V/STOL applications [SAE PAPER 872323] p 522 A88-37192 Development of lift ejectors for STOVL combat aircraft (SAE PAPER 872324) p 522 A88-37193 A numerical study of viscous flow in inlets and augmentors [AlAA PAPER 88-0187] p 495 A88-41092 THRUST VECTOR CONTROL The VAAC VSTOL flight control research project

Model study of thermal stresses in gas-turbine blades with protective coating p 542 N88-22989

with protective coating

p 497 N88-22011

nozzle [NASA-CR-182759]

# **THRUST-WEIGHT RATIO**

the second and a second and the second Thrust Voctor Control	TRAJECTORY OPTIMIZATION	Highlights of experience with a flexible walled test
Heat transfer modeling of jet vane Thrust Vector Control (TVC) systems	Numerical calculations of a class of optimal flight	section in the NASA Langley 0.3-meter transonic cryogenic
[AD-A190106] p 524 N88-22034	trajectories p 553 A88-38178	tunnel [AIAA PAPER 88-2036] p 533 A88-37938
THRUST-WEIGHT RATIO	TRANSFER FUNCTIONS  The calculation of the flow through a two-dimensional	Adaptive wall research with two- and three-dimensional
Impact of bypass ratio on thrust-to-weight for V/STOL  SAE PAPER 872348  p 523 A88-37237	faired diffuser p 485 A88-39030	models in low speed and transonic tunnels
TILT ROTOR AIRCRAFT	Experimental comparison of lightning simulation	[AIAA PAPER 88-2037] p 533 A88-37939
Powered-lift transport aircraft certification criteria	techniques to CV-580 airborne lightning strike	Two-dimensional and three-dimensional adaptation at the T2 transonic wind tunnel of Onera/Cert
status	measurements	[AIAA PAPER 88-2038] p 534 A88-37940
[SAE PAPER 872376] p 501 A88-37227 V-22 Osprey - Changing the way man flies	[AD-A190576] p 552 N88-22496	Mach number corrections for a two-foot propeller rig
p 514 A88-39277	TRANSFORMATIONS (MATHEMATICS)  Reduced order models for nonlinear aerodynamics	in solid and slotted test sections
Osprey's VSLED - Rewriting the maintenance manual	p 501 N88-23248	[AIAA PAPER 88-2056] p 534 A88-37946 Development of a control system for an injector powered
vibration, structural life, and engine diagnostics	TRANSITION FLOW	transonic wind tunnel
system p 474 A88-39325 Aircraft without airports - Changing the way men fly	Piezo-electric foils as a means of sensing unsteady	[AIAA PAPER 88-2063] p 535 A88-37950
tilt-rotor vehicles technology p 476 A88-40559	surface forces on flow-around bodies p 483 A88-38976	Theoretical and experimental analysis of the slotted-wall
Allison Gas Turbine - In the forefront of vertical flight	TRANSMISSIONS (MACHINE ELEMENTS)	flow field in a transonic wind tunnel [SAE PAPER 871757] p 482 A88-38775
propulsion R&D p 524 A88-40563	Computerized life and reliability modelling for turboprop	A transonic wind tunnel wall interference prediction
Improvements to tilt rotor performance through passive	transmissions	code
blade twist control [NASA-TM-100583] p 548 N88-22434	[NASA-TM-100918] p 551 N88-23220	[AIAA PAPER 88-2538] p 537 A88-40722
TILTING ROTORS	TRANSONIC COMPRESSORS Simulation of transonic flow in radial compressors	Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment
Using frequency-domain methods to identify XV-15	p 480 A88-37356	[NASA-TM-4032] p 538 N88-22047
aeroelastic modes LSAF PAPER 8723851 p 510 A88-37234	TRANSONIC FLOW	Aerofoil testing in a self-streamlining flexible walled wind
SAE PAPER 872385   p 510 A88-3/234   TIME DEPENDENCE	Simulation of transonic flow in radial compressors	tunnel
Short duration flow establishment on a profile in a	p 480 A88-37356	[NASA-CR-4128] p 499 N88-22865 The transonic wind tunnel (TWB) at DFVLR, Brunswick
Water-Ludwieg-Tunnel p 549 N88-23134	A comparison of numerical algorithms for unsteady transonic flow p 480 A88-37360	(Federal Republic of Germany)
Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow	transonic flow p 480 A88-3/360 Application of efficient iteration scheme AF2 to	IDFVLR-MITT-88-01  p 539 N88-22909
p 550 N88-23155	computations of transonic full-potential flows over	Flow quality of NAL two-dimensional transonic wind
TIME DIVISION MULTIPLE ACCESS	wing-body combinations p 481 A88-38177	tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction
Joint Tactical Information Distribution System (JTIDS)	Improvements on accuracy and efficiency for calculation	[NASA-TT-20209] p 539 N88-22911
class 2 terminal flight test	of transonic viscous flow around an airfoil	TRANSPONDERS
[AIAA PAPER 88-2119] p 505 A88-38720 TIME LAG	p 482 A88-38303 Transonic Fuler calculations of a wing-body	Taxiway safety using mode S SSR
Aerodynamic lag of a close-coupled canard aircraft	Transonic Euler calculations of a wing-body configuration using a high-accuracy TVD scheme	p 519 A88-39495 TRANSPORT AIRCRAFT
model at Mach 0.3 to 1.6	[AIAA PAPER 88-2547] p 488 A88-40729	Advanced tactical transport needs and design
[AIAA PAPER 88-2030] p 481 A88-37933 The effects of torque response and time delay on	PNS calculations of hypersonic transitional flow over	implications
rotorcraft vertical axis handling qualities	cones [AIAA PAPER 88-2565] p 490 A88-40738	[SAE PAPER 872337] p 473 A88-37205
[AD-A189873] p 515 N88-22023	[AlAA PAPER 88-2565] p 490 A88-40738 Three-dimensional unsteady transonic viscous-inviscid	VSTOL design implications for tactical transports [SAE PAPER 872338] p 473 A88-37206
TIME MARCHING	interaction using the Euler and boundary-layer equations	Powered-lift transport aircraft certification criteria
The 2-D and 3-D time marching transonic potential flow method for propfans p 501 N88-23245	[AIAA PAPER 88-2578] p 491 A88-40747	status
Reduced order models for nonlinear aerodynamics	Unsteady viscous-inviscid interaction procedures for	[SAE PAPER 872376] p 501 A88-37227
p 501 N88-23248	transonic airfoils using Cartesian grids	Flight test of the Japanese USB STOL experimental aircraft ASKA
TIME OF FLIGHT SPECTROMETERS  Littersonic Time-Of-Flight Diffraction (TOFD)	[/maii// =,	[AIAA PAPER 88-2180] p 513 A88-38750
Ultrasonic Time-Of-Flight Diffraction (TOFD) measurements of crack depths in an acceleration reservoir	Turbulent eddy viscosity modeling in transonic shock/boundary layer interactions	Taxiway safety using mode S SSR
of a high velocity research gun	[AIAA PAPER 88-2592] p 493 A88-40758	p 519 A88-39495
[DE88-006644] p 538 N88-22907	Calculations of three-dimensional flows using the	Trends and problems of head-up display p 519 A88-40534
TIP SPEED	isenthalpic Euler equations with implicit flux-vector splitting	Avionics for transport aircraft - Current development
Visualisation of the flow at the tip of a high speed axial flow turbine rotor	[AIAA PAPER 88-2516] p 493 A88-40762	status p 520 A88-41098
[AD-A189928] p 546 N88-22300	Computational simulation of vortex generator effects on	Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation
TITANIUM ALLOYS	transonic shock/boundary layer interaction	[NLR-MP-86074-U] p 498 N88-22017
Life of gas turbine engine disks with cracks p 544 A88-37549	[AIAA PAPER 88-2590] p 495 A88-40771 On the use of subcycling for solving the compressible	KRASH parametric sensitivity study: Transport category
TOLERANCES (MECHANICS)	Navier-Stokes equations by operator-splitting and finite	airplanes
A study of damage tolerance in curved composite	element methods p 495 A88-41269	[AD-A189962] p 515 N88-22024
panels	Computational fluid dynamics drag prediction: Results	TRIANGULATION  Taxiway safety using mode S SSR
[AD-A190617] p 541 N88-22092	from the Viscous Transonic Airfoil Workshop I NASA-TM-100095   p 496 N88-22009	p 519 A88-39495
TORQUE  The effects of torque response and time delay on	[NASA-TM-100095] p 496 N88-22009 Mixed direct-inverse problem of transonic cascade	TUNING
rotorcraft vertical axis handling qualities	p 498 N88-22244	Development of aeroelastic analysis methods for
[AD-A189873] p 515 N88-22023	Experimental investigation of the transonic flow at the	turborotors and propfans, including mistuning p 551 N88-23244
TRACKING (POSITION)  A new method to confirm category III autoland	leeward side of a delta wing at high incidence [LR-518] p 499 N88-22861	TUPOLEV AIRCRAFT
performance	The 2-D and 3-D time marching transonic potential flow	Tupolev Backfire p 514 A88-39504
[AIAA PAPER 88-2126] p 505 A88-38726	method for propfans p 501 N88-23245	TURBINE BLADES Factors affecting the temperature state of the blading
Multiple model parameter adaptive control for in-flight	TRANSONIC FLUTTER	of high-temperature turbines p 486 A88-40314
simulation (AD-A190568) p 537 N88-22044	A study of aeroelastic stability for the model support system of the National Transonic Facility	Model study of thermal stresses in gas-turbine blades
[AD-A190568] p 537 N88-22044 TRAILING EDGES	[AIAA PAPER 88-2033] p 533 A88-37936	with protective coating p 542 N88-22989
Experimental and numerical analysis of the formation	TRANSONIC SPEED	Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990
and evolution of streamwise vortices in the plane wake	Calculated viscous effects on airfoils at transonic	Lewis Structures Technology, 1988. Volume 1: Structural
behind a flat plate p 484 A88-39017	speeds [AIAA PAPER 88-2027] p 481 A88-37931	Dynamics
Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence	Calculation of transonic rotor noise using a frequency	[NASA-CP-3003-VOL-1] p 551 N88-23226
[LR-518] p 499 N88-22861	domain formulation p 555 A88-38380	TURBOCOMPRESSORS  The use of optimization technique and through flow
TRAINING AIRCRAFT	Boundary-layer stability analysis of NLF and LFC	analysis for the design of axial flow compressor stages
T-46A final report LAIAA PAPER 88-2092   p 511 A88-38709	experimental data at subsonic and transonic speeds [SAE PAPER 871859] p 483 A88-38925	p 477 A88-37112
[AIAA PAPER 88-2092] p 511 A88-38709 TRAJECTORY ANALYSIS	Theoretical investigations, and correlative studies for	Small engine components test facility turbine testing
Radarbet - A multiple trajectory estimator using an expert	NLF, HLFC, and LFC swept wings at subsonic, transonic	cell (NASA-TM-100887) p 525 N88-22037
system	and supersonic speeds (SAF PAPER 871861) p 483 A88-38950	[NASA-TM-100887] p 525 N88-22037 Supersonic axial-flow fan flutter p 552 N88-23255
[AIAA PAPER 88-2082] p 505 A88-38705	[SAE PAPER 871861] p 483 A88-38950 TRANSONIC WIND TUNNELS	TURBOFAN ENGINES
TRAJECTORY CONTROL  A forecast of new test capabilities using Magnetic	INCIDENTE THE PRINCES	Test stand performance of a convertible engine for
Suspension and Balance Systems	The AEDC 1-foot transonic wind tunnel - A useful	
	research and development facility	advanced V/STOL and rotorcraft propulsion
[AIAA PAPER 88-2013] p 532 A88-37921	research and development facility [AIAA PAPER 88-2001] p 531 A88-37912	advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217
[AIAA PAPER 88-2013] p 532 A88-37921 TRAJECTORY MEASUREMENT	research and development facility [AIAA PAPER 88-2001] p 531 A88-37912 Study on needs for a magnetic suspension system	advanced V/STOL and rotorcraft propulsion
[AIAA PAPER 88-2013] p 532 A88-37921	research and development facility [AIAA PAPER 88-2001] p 531 A88-37912	advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217 A survey of the flight testing and evaluation of CF M56

p 503 A88-37386

Turbofan engine core noise source diagnostics

p 478 A88-37211

p 538 N88-22050

[SAE PAPER 872345] USER REQUIREMENTS

[NASA-TM-100424]

Real-time flight test data distribution and display

UNIVERSITIES

p 524 A88-39707	shock/boundary layer interactions	The Rotorcraft Center of Excellence at the University
Thermal state of a turbofan rotor p 545 A88-40317	(AIAA PAPER 88-2592) p 493 A88-40758	of Maryland p 475 A88-40556
Linear state space modeling of a turbofan engine	Turbulent reacting flows and supersonic combustion [AD-A189690] p 541 N88-22115	UNSTEADY AERODYNAMICS
[AD-A190110] p 524 N88-22035	[AD-A189690] p 541 N88-22115 Describing the source created by turbulent flow over	Unsteady features of jets in lift and cruise modes for VTOL aircraft
Noise assessment of unsuppressed TF-34-GE-100A engine at Warfield ANG, Baltimore, Maryland	orifices and louvers	[SAE PAPER 872359] p 478 A88-37220
[AD-A189966] p 556 N88-22702	[AD-A190254] p 556 N88-22706	A comparison of numerical algorithms for unsteady
TURBOMACHINE BLADES	Experimental studies of vortex flows	transonic flow p 480 A88-37360
Numerical calculations of the natural vibrations of	[NASA-CR-182874] p 551 N88-23171	Aerodynamic lag of a close-coupled canard aircraft
turbomachine blades using the finite element method	TURBULENT JETS Computer simulation of turbulant into and walker	model at Mach 0.3 to 1.6
p 523 A88-37543	Computer simulation of turbulent jets and wakes p 544 A88-37661	[AIAA PAPER 88-2030] p 481 A88-37933
TURBOMACHINERY	Axisymmetric turbulent compressible jet in subsonic	Wind tunnel interference on unsteady two-dimensional
Aeroelastic forced response analysis of	coflow p 480 A88-37665	aerofoil motions in low speed flows p 535 A88-38169
turbomachinery p 526 N88-23247 TURBOPROP AIRCRAFT	LDV measurements on impinging twin-jet fountain flows	Fluid mechanics of dynamic stall. I - Unsteady flow
Scale model acoustic testing of counterrotating fans	with a simulated fuselage undersurface	concepts p 485 A88-39511
[AIAA PAPER 88-2057] p 523 A88-37947	p 484 A88-38986 The turbulence characteristics of a single impinging jet	Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer
Mechanisms of active control for noise inside a vibrating	through a crossflow p 545 A88-39012	p 486 A88-40421
cylinder p 555 A88-39722	The structure of sonic underexpanded turbulent air jets	Research at Rensselaer Polytechnic Institute's Center
Active control of sound fields in elastic cylinders by	in still air	of Excellence in rotorcraft technology
vibrational inputs p 556 A88-39725	[AD-A190856] p 500 N88-22870	p 475 A88-40557
NASA advanced turboprop research and concept	TURBULENT MIXING	Unsteady aerodynamics of a Wortmann FX-63-137 wing
validation program	Experimental studies of vortex flows	in a fluctuating wind field
[NASA-TM-100891] p 526 N88-22902	[NASA-CR-182874] p 551 N88-23171 TURBULENT WAKES	[AD-A190128] p 496 N88-22006
TURBOPROP ENGINES	Computer simulation of turbulent jets and wakes	Bifurcations in unsteady aerodynamics-implications for
Large-scale model for experimental wind tunnel investigations p 531 A88-37298	p 544 A88-37661	testing [NASA-TM-100083] p 497 N88-22014
Computerized life and reliability modelling for turboprop	Computational study of the unsteady flow due to wakes	[NASA-TM-100083] p 497 N88-22014 UNSTEADY FLOW
transmissions	passing through a channel p 483 A88-38984	Unsteady features of jets in lift and cruise modes for
[NASA-TM-100918] p 551 N88-23220	Properties of a half-delta wing vortex	VTOL aircraft
Development of aeroelastic analysis methods for	p 483 A88-38985 On a least-energy hypothesis for the wake of	[SAE PAPER 872359] p 478 A88-37220
turborotors and propfans, including mistuning	axisymmetric bodies with turbulent separation -	A comparison of numerical algorithms for unsteady
p 551 N88-23244	Pressure-distribution prediction	transonic flow p 480 A88-37360
Vibration and flutter analysis of the SR-7L large-scale	[AIAA PAPER 88-2513] p 487 A88-40705	Computational study of the unsteady flow due to wakes
propfan p 551 N88-23254	TWO DIMENSIONAL BODIES	passing through a channel p 483 A88-38984
TURBOSHAFTS	Wind tunnel interference on unsteady two-dimensional	Numerical simulation of wings in steady and unsteady
Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion	aerofoil motions in low speed flows p 535 A88-38169 TWO DIMENSIONAL FLOW	ground effects [AIAA PAPER 88-2546] p 488 A88-40728
[SAE PAPER 872355] p 523 A88-37217	Correlation of entrainment and lift enhancement for a	[AIAA PAPER 88-2546] p 488 A88-40728 Visualization and anemometry analyses of forced
TURBULENCE	two-dimensional propulsive wing	unsteady flows about an X-29 model
Turbulence and fluid/acoustic interaction in impinging	[SAE PAPER 872325] p 477 A88-37194	[AIAA PAPER 88-2570] p 490 A88-40741
jets	Review of transition effects on the problem of dynamic	Pitch rate and Reynolds number effects on a pitching
[SAE PAPER 872345] p 478 A88-37211	simulation of wind tunnel tests	rectangular wing
On the validation of a code and a turbulence model	[AIAA PAPER 88-2004] p 532 A88-37915	[AIAA PAPER 88-2577] p 491 A88-40746
appropriate to circulation control airfoils [NASA-TM-100090] p 499 N88-22864	Highlights of experience with a flexible walled test section in the NASA Langley 0.3-meter transonic cryogenic	Three-dimensional unsteady transonic viscous-inviscid
TURBULENCE EFFECTS	tunnel	interaction using the Euler and boundary-layer equations [AIAA PAPER 88-2578] p 491 A88-40747
Estimation of turbulence effects on sound propagation	(AIAA PAPER 88-2036) p 533 A88-37938	[AIAA PAPER 88-2578] p 491 A88-40747 Unsteady aerodynamic forces at low airfoil pitching
from low flying aircraft p 555 A88-39712	Adaptive wall research with two- and three-dimensional	rates
TURBULENCE METERS	models in low speed and transonic tunnels	[AIAA PAPER 88-2579] p 492 A88-40748
METEOPOD, an airborne system for measurements of	[AIAA PAPER 88-2037] p 533 A88-37939	Impingement of orthogonal unsteady vortex structures
mean wind, turbulence, and other meteorological parameters	Two-dimensional and three-dimensional adaptation at the T2 transonic wind tunnel of Onera/Cert	on trailing aerodynamic surfaces
[AIAA PAPER 88-2103] p 519 A88-38715	[AIAA PAPER 88-2038] p 534 A88-37940	[AIAA PAPER 88-2580] p 492 A88-40749
Measurements of turbulent flow behind a wing-body	The use of 2-D adaptive wall test sections for 3-D	Unsteady flow interactions between the wake of an oscillating airfoil and a stationary trailing airfoil
junction p 484 A88-38987	flows	[AIAA PAPER 88-2581] p 492 A88-40750
TURBULENT BOUNDARY LAYER	[AIAA PAPER 88-2041] p 534 A88-37943	A comparative study of differing vortex structures arising
Turbulent friction on a delta wing p 480 A88-37657	Separation and reattachment near theleading edge of	in unsteady separated flows
A real-time aerodynamic analysis system for use in flight	a thin wing p 486 A88-39967 Flow past two-dimensional ribbon parachute models	[AIAA PAPER 88-2582] p 492 A88-40751
[AIAA PAPER 88-2128] p 512 A88-38728	(AIAA PAPER 88-2524) p 488 A88-40714	Unsteady viscous-inviscid interaction procedures for
Measurements in a three-dimensional turbulent	Flexiwall 3 SO: A second order predictive strategy for	transonic airfoils using Cartesian grids [AIAA PAPER 88-2591] p 493 A88-40757
boundary-layer p 484 A88-39000	rapid wall adjustment in two-dimensional compressible	Unsteady nonsimilar laminar compressible
Detection of large-scale organized motions in a turbulent	flow	boundary-layer flow over a yawed infinite circular
boundary layer p 484 A88-39023	[NASA-CR-181662] p 498 N88-22018	cylinder p 495 A88-40970
Experimental study of a supersonic turbulent boundary layer using a laser Doppler anemometer		Unsteady aerodynamics of a Wortmann FX-63-137 wing
p 485 A88-39623	U	in a fluctuating wind field
Observation of three-dimensional 'separation' in shock		[AD-A190128] p 496 N88-22006 Oscillating airfoils: Achievements and conjectures
wave turbulent boundary layer interactions	UH-60A HELICOPTER	[AD-A190490] p 496 N88-22008
p 486 A88-39952	Preliminary airworthiness evaluation of the UH-60A with	Measurements of aerodynamic forces on unsteadily
Unsteady aerodynamic heating phenomena in the	Advanced Digital Optical Control System (ADOCS) [AD-A190674] p 516 N88-22030	moving bluff parachute canopies p 549 N88-23137
interaction of shock wave/turbulent boundary layer p 486 A88-40421	Airworthiness and flight characteristics test of a ski	UPGRADING
Modelling the influence of small surface discontinuities	assembly for the UH-60A Black Hawk helicopter	Effects of update and refresh rates on flight simulation
in turbulent boundary layers	(AD-A191414) p 518 N88-22895	visual displays [NASA-TM-100415] p 516 N88-22033
[AIAA PAPER 88-2594] p 546 A88-40759	ULLAGE	[NASA-TM-100415] p 516 N88-22033 UPPER SURFACE BLOWING
Numerical and experimental investigation of multiple	Development and evaluation of an airplane fuel tank	Correlation of entrainment and lift enhancement for a
shock wave/turbulent boundary layer interactions in a	ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions	two-dimensional propulsive wing
rectangular duct [AD-A190772] p 547 N88-22320	[AD-A190408] p 515 N88-22025	[SAE PAPER 872325] p 477 A88-37194
[AD-A190772] p 547 N88-22320 Aerothermal tests of quilted dome models on a flat plate	ULTRASONIC TESTS	Stability and control augmentation system of 'ASKA'
at a Mach number of 6.5	Ultrasonic Time-Of-Flight Diffraction (TOFD)	[SAE PAPER 872334] p 527 A88-37203 UPPER SURFACE BLOWN FLAPS
[NASA-TP-2804] p 547 N88-22325	measurements of crack depths in an acceleration reservoir	Flight test of the Japanese USB STOL experimental
TURBULENT FLOW	of a high velocity research gun	aircraft ASKA
Numerical separation models p 480 A88-37653	[DE88-006644] p 538 N88-22907	[AIAA PAPER 88-2180] p 513 A88-38750
Measurements of turbulent flow behind a wing-body	Nondestructive evaluation of large scale composite	UPWASH
junction p 484 A88-38987 Flow in out-of-plane double S-bends	components [AD-A190998] p 542 N88-22954	Turbulence and fluid/acoustic interaction in impinging
		iets

p 484 A88-39011

p 486 A88-39952

Observation of three-dimensional 'separation' in shock

wave turbulent boundary layer interactions

UNITED STATES

Aircraft accident reports, brief format, US civil and foreign

p 502 N88-22020

aviation, issue number 10 of 1986 accidents [PB87-916912] p 502

Turbulent eddy viscosity modeling in transonic

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International Powered Lift Conference and Exposition,
Santa Clara, CA, Dec. 7-10, 1987, Proceedings   SAE P-203   p 473 A88-37176
Hover suckdown and fountain effects encountered
by V/STOL aircraft [SAE PAPER 872305] p 477 A88-37177
Hot gas recirculation in V/STOL
Landing surface characteristics unique to V/STOL
aircraft
SAE PAPER 872310  p 530 A88-37182
V/STOL and the Royal Air Force
[SAE PAPER 872319] p 508 A88-37189
Advances in ejector thrust augmentation
SAE PAPER 872322  p 522 A88-37191
Estimation of thrust augmentor performance in V/STOL
applications
[SAE PAPER 872323] p 522 A88-37192
Experimental investigation of a jet impinging on a ground
plane in the presence of a cross flow
[SAE PAPER 872326] p 478 A88-37195
Thrust efficiency of powered lift systems
[SAE PAPER 872327] p 522 A88-37196
Integrated control and display research for transition and
vertical flight on the NASA V/STOL Research Aircraft
(VSRA)
[SAE PAPER 872329] p 526 A88-37198
Flight propulsion control integration for V/STOL
aircraft USAE PAPER 8723301 p. 522 A88-37199
[CAL 174 Et l'O'LOGO)
The VAAC VSTOL flight control research project Vectored thrust Aircraft Advanced flight Control
SAE PAPER 872331   p 526 A88-37200   VSTOL design implications for tactical transports
[SAE PAPER 872338] p 473 A88-37206
Numerical investigation of a jet in ground effect with a
crossflow
[SAE PAPER 872344] p 478 A88-37210
STOVL RCS effects on propulsion system design
[SAE PAPER 872349] p 522 A88-37214
NASA supersonic STOVL propulsion technology
program
[SAE PAPER 872352] p 523 A88-37215
Test stand performance of a convertible engine for
advanced V/STOL and rotorcraft propulsion
[SAE PAPER 872355] p 523 A88-37217
Results of a precision hover simulation on the one-to-one
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator   SAE PAPER 872356   p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations   SAE PAPER 872372   p 501 A88-37226
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 Impact of bypass ratio on thrust-to-weight for V/STOL
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872348] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [mpact of bypass ratio on thrust-to-weight for V/STOL SAE PAPER 872348] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [mpact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872344] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872348] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 509 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL SAE PAPER 872341] p 572 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872344] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37231 [SAE PAPER 872341] p 579 A88-37231 [SAE PAPER 872341] p 579 A88-37237 [SIGNED ASSET STOLE SAE PAPER 872348] p 523 A88-37237 [SIGNED ASSET STOLE SAE PAPER 872348] p 523 A88-37237 [SIGNED ASSET STOLE SAE PAPER 872348] p 523 A88-37237 [SIGNED ASSET STOLE SAE PAPER 872348] p 512 A88-38731 [SIGNED ASSET SAE
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 Impact of bypass ratio on thrust-to-weight for V/STOL SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL SAE PAPER 872348] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872381] p 509 A88-37231 [SAE PAPER 872381] p 570 A88-37231 [SAE PAPER 872381] p 570 A88-37231 [SAE PAPER 872341] p 570 A88-37237 [SIGH PAPER 872341] p 570 A88-37237 [SIGH PAPER 872348] p 523 A88-37237 [SIGH PAPER 872348] p 523 A88-37237 [SIGH PAPER 88-2134] p 512 A88-38731 [Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-2] p 500 N88-22866 [Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 [Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 [Propulsion and airframe aerodynamic interactions of supersonic v/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 [Propulsion and airframe aerodynamic interactions of supersonic v/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 [Propulsion and airframe aerodynamic interactions of supersonic v/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 [Propulsion and airframe aerodynamic interactions of supersonic v/STOL configurations. Volume 2: Wind tunnel test force and moment data report [VASA-CR-177343-VOL-2]
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AlAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [INASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [INASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL SAE PAPER 872341] p 529 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872381] p 570 A88-37231 [SAE PAPER 872341] p 479 A88-37231 [SAE PAPER 872341] p 479 A88-37231 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872348] p 523 A88-37237 [Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES  Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872348] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary INASA-CR-177343-VOL-2] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES  Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES  Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217 Determination of the aerodynamic characteristics of the
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES  Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217 Determination of the aerodynamic characteristics of the Mission Adaptive Wing
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37231 [SAE PAPER 872341] p 509 A88-37231 [SAE PAPER 872341] p 523 A88-37237 [Sight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary INASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary INASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 500 N88-22868 PAPER 872355] p 523 A88-37217 Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37231 [SAE PAPER 872341] p 509 A88-37231 [SAE PAPER 872341] p 523 A88-37237 [Sight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary INASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary INASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 500 N88-22868 PAPER 872355] p 523 A88-37217 Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872348] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary INASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary INASA-CR-177343-VOL-2] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES  Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217 Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733 VARIABLE PITCH PROPELLERS  The effects of forque response and time delay on rotorcraft vertical axis handling qualities
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22867 Propulsion and airframe aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 87-2355] p 523 A88-37217 Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733 VARIABLE PITCH PROPELLERS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AlAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 VARIABLE GEOMETRY STRUCTURES  Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion [SAE PAPER 872355] p 523 A88-37217 Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AlAA PAPER 88-2556] p 489 A88-40733 VARIABLE PITCH PROPELLERS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] VARIABLE SWEEP WINGS
Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator [SAE PAPER 872356] p 509 A88-37218 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] p 509 A88-37230 A supersonic design with V/STOL capability [SAE PAPER 872381] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872382] p 509 A88-37231 Application of empirical and linear methods to VSTOL powered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236 [Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872341] p 523 A88-37237 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model [AIAA PAPER 88-2134] p 512 A88-38731 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report [NASA-CR-177343-VOL-1] p 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-2] p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22867 Propulsion and airframe aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 87-2355] p 523 A88-37217 Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733 VARIABLE PITCH PROPELLERS  The effects of torque response and time delay on rotorcraft vertical axis handling qualities [AD-A189873] p 515 N88-22023

	VARIATIONAL PRINCIPLES			
n	Development of a variational metho sensitivity analysis	p 541		
n, 76	VEHICLES  Vehicles and aircraft on floating ice	e p 536	S A88-	400
ed	VELOCITY DISTRIBUTION			
77	Experimental investigation on rigid liparachute model in accelerating and		flow	
78 )L	The turbulence characteristics of a through a crossflow	single p 545		
32	High Reynolds number, low Mach field calculations over a NACA	0012	airfoil	us
39	Navier-Stokes and interactive bound [AD-A189871]	p 496	N88-	220
91 DL	Unsteady aerodynamics of a Worth in a fluctuating wind field	nann Fi p 496		
92 nd	[AD-A190128]  Boundary-layer and wake measur circulation-control wing			
95	NASA-TM-89426  Measurements of the time dep	p 497 endent		
96	surrounding a model propeller in unit		ater flov	N
nd aft	VERTICAL FLIGHT Integrated control and display reseavertical flight on the NASA V/STO			
98 OL	(VSRA) [SAE PAPER 872329]		6 A88	
99	Aircraft without airports - Changing tilt-rotor vehicles technology VERTICAL LANDING	g the w	Ay mer	1 fly -405
00	International Powered Lift Confere Santa Clara, CA, Dec. 7-10, 1987, P	roceed	ings	
06	[SAE P-203] The ground environment created by		3 A88- specific	
10	vertical land aircraft [SAE PAPER 872309]	p 47		
14	Development of lift ejectors for ST  SAE PAPER 872324  Propulsion/aerodynamic integratio	p 52	2 A88	-37
gy	aircraft Advanced Short Take- [SAE PAPER 872333]		ertical L	and
15 for	STOVL RCS effects on propulsion [SAE PAPER 872349]	syster p 52	m desig 2 A88	n -37:
17 ne	Aeroacoustics of advanced ST  SAE PAPER 872358  STOVL acoustic fatigue technolog	p 55 jies	4 A88	-37
18	[SAE PAPER 872360] The synthesis of ejector lift/vector		ust for :	STC
ed 26	[SAE PAPER 872378] Configuration E-7 supersonic 5 technology program	p 52 STOVL		
in	[SAE PAPER 872379] Wave drag and high-speed perfor	p 50		
30	STOVL fighter configurations [SAE PAPER 872311]	p 47		
31 OL	Overview of the US/UK ASTOVL [SAE PAPER 872365]	p 47	3 A88	-37:
36	Parametric study of superso characteristics		STOVL	fl
37	[NASA-CR-177330] VERTICAL ORIENTATION	p 51		
ре 31	The effects of torque response rotorcraft vertical axis handling quali	ities		
of nel	[AD-A189873]  VERTICAL TAKEOFF  International Powered Lift Conference  International Powered Lif	p 51 ence a		
66	Santa Clara, CA, Dec. 7-10, 1987, P		lings	
of nel	Landing surface characteristic			
67	[SAE PAPER 872310] VERTICAL TAKEOFF AIRCRAFT	p 53		
of ary	Propulsion-induced effects cause effects			
68 for	[SAE PAPER 872307] Lift engines - Applied history [SAE PAPER 872347]	р 47 р 52		
17	Unsteady features of jets in lift a VTOL aircraft	ınd cru	ise moi	des
he	[SAE PAPER 872359] VIBRATION	p 47		
33 on	Modal forced response of propfar  VIBRATION DAMPING	ns in ya p 55		
23	Using frequency-domain metho aeroelastic modes	ds to	identify	ΧV
on	[SAE PAPER 872385]		0 A88	

[NASA-CP-3003-VOL-1]

rotating machinery

Piezoelectric pushers for active vibration control of

p 551 N88-23229

p 513 A88-38762

```
Active control and system identification of rotordynamic
                          etructure
                                                              p 551 N88-23230
                        VIBRATION EFFECTS
               190
                            The effect of aircraft angular vibrations on the quality
                          of remotely sensed images
                                                              p 520 A88-41096
                        VIBRATION MODE
               66
                            Numerical calculations of the natural vibrations of
                          turbomachine blades using the finite element method
               ical
                                                               p 523 A88-37543
                            Assessment of transient testing techniques for rotor
                85
                          stability testing
                          AIAA PAPER 88-2401
                                                               p 546 A88-40871
                12
                        VIBRATION TESTS
               low
                            Development of a block Lanczos algorithm for free
                ing
                          vibration analysis of spinning structures
                                                               p 545 A88-40117
               105
                        VIDEO EQUIPMENT
                ing
                            Power supply for an easily reconfigurable connectorless
                          passenger-aircraft entertainment system
                006
                                                              p 513 A88-38800
                        VISCOUS FLOW
               ept,
                            Calculated viscous effects on airfoils at transonic
               13
                          [AIAA PAPER 88-2027]
               ield
                            Velocity profile similarity for viscous flow development
                55
                          along a longitudinally slotted wind-tunnel wall
                          | AIAA PAPER 88-2029 |
                            Improvements on accuracy and efficiency for calculation
                and
                          of transonic viscous flow around an airfoil
               raft
                                                               p 482 A88-38303
                            Flow analysis around aircraft by viscous flow omputation p 482 A88-38343
                98
                          computation
                            Unsteady viscous-inviscid interaction procedures for
                559
                           transonic airfoils using Cartesian grids
                                                               p 493 A88-40757
                          [AIAA PAPER 88-2591]
               on.
                            A numerical study of viscous flow in inlets and
                           augmentors
                176
                          [AIAA PAPER 88-0187]
                                                               p 495 A88-41092
               rust
                            Computational fluid dynamics drag prediction: Results
                           from the Viscous Transonic Airfoil Workshop
                181
                                                              p 496 N88-22009
                          |NASA-TM-100095|
                raft
                        | NASA-TM-100095| p 496 N88-22009
| Theoretical model and numerical solution for
| compressible viscous vortex cores p 498 N88-22243
| VOICE COMMUNICATION
                93
               bat
                ling
                             Implementation of aeronautical mobile satellite services
               202
                                                               p 506 A88-40519
                           (AMSSs)
                         VORTEX ALLEVIATION
               214
                             The characteristics of asymmetric vortices and side
                           forces on a sharp-nosed body with wing and vertical tail
               219
                                                              p 482 A88-38188
                        VORTEX BREAKDOWN
               221
                           Wing vortex-flows up into vortex breakdown - A numerical simulation
               DVL
                                                               p 487 A88-40709
                          [AIAA PAPER 88-2518]
               ack
                            Investigation on the movement of vortex burst position
                           with dynamically changing angle of attack for a schematic
               229
                           deltawing in a watertunnel with correlation to similar studies
               nnic
                                                               p 550 N88-23152
                           in windtunnel
                         VORTEX FILAMENTS
               235
                             Experimental investigation of topological structures in
                                                               p 486 A88-39970
                           three-dimensional separated flow
               238
                         VORTEX FLAPS
               ight
                             Prediction of vortex lift of non-planar wings by the
                         leading-edge suction analogy VORTEX GENERATORS
                                                               p 485 A88-39279
               893
                             Properties of a half-delta wing vortex
                on
                                                               p 483 A88-38985
                             Time-dependent structure in wing-body junction flows
               023
                             Computational simulation of vortex generator effects on
               ion,
                           transonic shock/boundary layer interaction
                                                               p 495 A88-40771
                           [AIAA PAPER 88-2590]
               176
                                          Navier-Stokes
                             Transonic
                                                              computations
                OL
                           strake-generated vortex interactions for a fighter-like
                           configuration
               182
                           | NASA-TM-100009|
                                                               p 497 N88-22010
                            Experimental studies of vortex flows
               und
                                                               p 551 N88-23171
                           [NASA-CR-182874]
               179
                         VORTEX SHEDDING
                            Recent developments and engineering applications of
                           the vortex cloud method
               213
                             Wing vortex-flows up into vortex breakdown - A
                for
                           numerical simulation
                           [AIAA PAPER 88-2518]
                                                               p 487 A88-40709
               220
                             On the prediction of highly vortical flows using an Euler
                           equation model, part 2
                                                               p 547 N88-22305
                           [AD-A190245]
               253
                             Stall flutter analysis of propfans p 552 N88-23256
                         VORTEX SHEETS
                '-15
                             A multilifting line method and its application in design
                           and analysis of nonplanar wing configurations
               234
                           [DFVLR-FB-87-51]
                                                               p 499 N88-22860
                         VORTICES
p 551 N88-23226
                             Measurement of leading edge vortices from a delta wing
```

using a three component laser velocimeter

[AIAA PAPER 88-2024]

p 544 A88-37929

[AIAA PAPER 88-2110]

Influence of unsteady aerodynamic forces on dynamic

response of variable sweep aircraft p 516 N88-22245

Visualization techniques for studyin separated vortical flows	g high angle of attack
[AIAA PAPER 88-2025]	p 544 A88-37930
Visualization and wake surveys of delta wing	vortical flow over a p 482 A88-38377
Detection of large-scale organized r	motions in a turbulent
boundary layer Comparison of Euler and Navier-	p 484 A88-39023
vortex flow over a delta wing	p 485 A88-39278
Applications of an Euler aerod	lynamic method to
free-vortex flow simulation [AIAA PAPER 88-2517]	p 487 A88-40708
Leading edge vortex dynamics	
wing TAIAA PAPER 88-25591	p 489 A88-40735
A method to increase the accura	
simulations [AIAA PAPER 88-2562]	p 490 A88-40736
Experimental and numerical invest	•
flow over a yawed delta wing [AIAA PAPER 88-2563]	- 400 A00 40707
Pitch rate and Reynolds number e	p 490 A88-40737 effects on a pitching
rectangular wing	
[AIAA PAPER 88-2577] A comparative study of differing vor	p 491 A88-40746
in unsteady separated flows	·
[AIAA PAPER 88-2582]  Nonintrusive measurements of vo	p 492 A88-40751
wings in a water tunnel	intex nows on delta
[AIAA PAPER 88-2595]	p 493 A88-40760
Further analysis of wing rock ger vortices	ierated by forebody
[AIAA PAPER 88-2597]	p 494 A88-40768
Experimental investigation of a spa layer	inwise forced mixing
[AD-A190136]	p 496 N88-22007
Transonic Navier-Stokes of strake-generated vortex interaction	computations of some some of some some some some some some some some
configuration	
[NASA-TM-100009]  Pressure measurements of impinging	p 497 N88-22010
nozzle	
[NASA-CR-182759] Investigation of combustion in large	p 497 N88-22011
[AD-A190406]	p 541 N88-22121
Theoretical model and nume compressible viscous vortex cores	
On the prediction of highly vortical	
equation model, part 2 [AD-A190245]	-
A numerical model of unsteady, s	p 547 N88-22305 subsonic aeroelastic
behavior	
[NASA-TM-101126] Vortex breakdown and control	p 499 N88-22862 experiments in the
Ames-Dryden water tunnel	p 549 N88-23127
Flow visualization study of vortex ma configurations at high angles of attack	k .
Experimental studies of vortex flow	p 549 N88-23130 s
[NASA-CR-182874]	p 551 N88-23171
VORTICITY Experimental and numerical analys	sis of the formation
and evolution of streamwise vortices	in the plane wake
behind a flat plate	p 484 A88-39017
W	

### WAKES

Boundary-layer and wake measurements on a swept, circulation-control wing INASA-TM-894261 p 497 N88-22013

WALL FLOW

Optimum porosity for an inclined-hole transonic test section wall treated for edgetone noise reduction

[AIAA PAPER 88-2003] p 531 A88-37914 Wind tunnel interference on unsteady two-dimensional aerofoil motions in low speed flows p 535 A88-38169

WALL PRESSURE

Theoretical and experimental analysis of the slotted-wall flow field in a transonic wind tunnel

[SAE PAPER 871757] p 482 A88-38775

**WALL TEMPERATURE** 

Heating requirements and nonadiabatic surface effects

for a model in the NTF cryogenic wind tunnel [AIAA PAPER 88-2044] p 534 A88-37944 WALLS

Structural analyses of engine wall cooling concepts and materials p 542 N88-22405

### WATER IMMERSION

Experimental investigation of Hover flowfields in water at the McDonnell Douglas Research Laboratories p 549 N88-23135

### WATER TUNNEL TESTS

Experimental investigation on rigid hollow hemispherical parachute model in accelerating and steady flow

p 482 A88-38185 The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration

p 536 A88-39525 IAIAA PAPER 88-20451 Nonintrusive measurements of vortex flows on delta wings in a water tunnel (AIAA PAPER 88-2595) p 493 A88-40760

Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Vortex breakdown and control experiments in the Ames-Dryden water tunnel p 549 N88-23127

Qualification of a water tunnel for force measurements on aeronautical models p 539 N88-23128 An experimental study to determine the flow and the subsonic static and dynamic stability characteristics of aircraft operating at high angles-of-attack

p 518 N88-23129 The use of the NRC/NAE water facilities in Canadian aeronautical research and development

p 539 N88-23132 Short duration flow establishment on a profile in a p 549 Water-Ludwieg-Tunnel Investigation on the movement of vortex burst position with dynamically changing angle of attack for a schematic deltawing in a watertunnel with correlation to similar studies windtunnel p 550 N88-23152
Measurements of the time dependent velocity field in windtunnel

surrounding a model propeller in uniform water flow p 550 N88-23155

### WATER VAPOR

Aircraft observation of the specific humidity and process of the water vapor transfer in the upper mixed boundary p 552 A88-39508

**WAVE DRAG** 

Wave drag and high-speed performance of supersonic STOVL fighter configurations

ISAE PAPER 872311] p 479 A88-37235 WAVE INTERACTION

Nonlinear wave interactions in swept wing flows (NASA-CR-4142 p 550 N88-23160 **WAVE REFLECTION** 

Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves

p 486 A88-40375

### WEAPON SYSTEMS

Air Force One replacement program - An application of acquisition streamlining and Federal Aviation Administration Certification

[AIAA PAPER 88-2123] p 474 A88-38723 Reliability and maintainability evaluation during flight

[AIAA PAPER 88-2185] p 474 A88-38754

# WEATHER FORECASTING

Aircraft accident/incident summary reports: Modena, Pennsylvania, March 17, 1986; Redwater, Texas, April 4, 1986

[PB88-910403] p 502 N88-22878

WEDGE FLOW

Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves

p 486 A88-40375 **WEIGHT ANALYSIS** The initial calculation of range and mission fuel during

conceptual design --- aircraft design p 517 N88-22889

### WEIGHT REDUCTION

Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-1005691 p 517 N88-22892

WIND (METEOROLOGY)

An interactive method for modifying numerical model wind forecasts p 552 A88-38679

# WIND MEASUREMENT

METEOPOD, an airborne system for measurements of mean wind, turbulence, and other meteorological parameters

AIAA PAPER 88-21031 p 519 A88-38715

# WIND PROFILES

An interactive method for modifying numerical model vind forecasts p 552 A88-38679

# WIND TUNNEL MODELS

A review of Magnetic Suspension and Balance Systems [AIAA PAPER 88-2008] n 532 A88-37917

A study of aeroelastic stability for the model support system of the National Transonic Facility

p 533 A88-37936 TAIAA PAPER 88-2033 L Adaptive wall research with two- and three-dimensional models in low speed and transonic tunnels

p 533 A88-37939 [AIAA PAPER 88-2037] A flow-transfer device with nonmetallic diaphragms for propulsion wind tunnel models [AIAA PAPER 88-2048]

p 534 A88-37945

Development of a control system for an injector powered

p 535 A88-37950 [AIAA PAPER 88-2063]

Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 Visualization and anemometry analyses of forced

unsteady flows about an X-29 model [AIAA PAPER 88-2570] p 490 A88-40741 Inflow measurement made with a laser velocimeter on a helicopter model in forward flight, Volume 3: Rectangular

planform blades at an advance ratio of 0.30 [NASA-TM-100543] Acoustic characteristics of 1/20-scale model helicopter rotors

[NASA-CR-177355] p 557 N88-23548

### WIND TUNNEL TESTS

Correlation of entrainment and lift enhancement for a two-dimensional propulsive wing

ISAE PAPER 8723251 p 477 A88-37194 Experimental investigation of a jet impinging on a ground plane in the presence of a cross flow

[SAF PAPER 8723261 p 478 A88-37195 Aerodynamic flow quality and acoustic characteristics

of the 40- by 80-foot test section circuit of the National Full-Scale Aerodynamic Complex [SAE PAPER 872328] p 530 A88-37197

Large-scale model for experimental wind tunnel vestigations p 531 A88-37298 Aerodynamic Testing Conference, 15th, San Diego, CA, investigations May 18-20, 1988, Technical Papers p 531 A88-37907 A plan for coupling wind tunnel testing with CFD

techniques [AIAA PAPER 88-1996] p 531 A88-37909 The Basic Aerodynamics Research Tunnel - A facility

dedicated to code validation [AIAA PAPER 88-1997] p 531 A88-37910 The AEDC 1-foot transonic wind tunnel - A useful

research and development facility [AIAA PAPER 88-2001] p 531 A88-37912 Review of transition effects on the problem of dynamic

simulation --- of wind tunnel tests [AIAA PAPER 88-2004] p 532 A88-37915 On hypersonic transition testing and prediction

[AIAA PAPER 88-2007] p 532 A88-37916 A review of Magnetic Suspension and Balance

Systems [AIAA PAPER 88-2008] p 532 A88-37917

An experimental investigation of the aerodynamic characteristics of slanted base ogive cylinders using magnetic suspension technology [AIAA PAPER 88-2011] p 481 A88-37919

Progress towards extreme attitude testing with Magnetic Suspension and Balance Systems [AIAA PAPER 88-2012] p 532 A88-37920

A forecast of new test capabilities using Magnetic Suspension and Balance Systems

[AIAA PAPER 88-2013] p 532 A88-37921 Study on needs for a magnetic suspension system operating with a transonic wind tunnel

[AIAA PAPER 88-2014] p 533 A88-37922 Aerodynamic lag of a close-coupled canard aircraft model at Mach 0.3 to 1.6

[AIAA PAPER 88-2030] p 481 A88-37933 A study of aeroelastic stability for the model support system of the National Transonic Facility

[AIAA PAPER 88-2033] p 533 A88-37936 An experimental investigation of flowfield about a

multielement airfoil [AIAA PAPER 88-2035] p 481 A88-37937

Highlights of experience with a flexible walled test section in the NASA Langley 0.3-meter transonic cryogenic tunnel

[AIAA PAPER 88-2036] p 533 A88-37938 Two-dimensional and three-dimensional adaptation at

the T2 transonic wind tunnel of Onera/Cert p 534 A88-37940 [AIAA PAPER 88-2038]

The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942

The use of 2-D adaptive wall test sections for 3-D

[AIAA PAPER 88-2041] p 534 A88-37943 A flow-transfer device with nonmetallic diaphragms for

propulsion wind tunnel models [AIAA PAPER 88-2048] p 534 A88-37945 Flow analysis around aircraft by viscous flow omputation p 482 A88-38343 computation

Use of dynamically scaled models for studies of the high-angle-of-attack behavior of airplanes

p 535 A88-38692 Boundary-layer stability analysis of NLF and LFC experimental data at subsonic and transonic speeds [SAE PAPER 871859] p 483 A88-38925

The integration of wind tunnel and water tunnel results for a new in-flight simulator configuration [AIAA PAPER 88-2045] p 536 A88-39525

# 

WIND TUNNEL WALLS
Wind tunnel investigation of wing-in-ground effects [AIAA PAPER 88-2527] p 488 A88-40716
A transonic wind tunnel wall interference prediction code [AIAA PAPER 88-2538] p 537 A88-40722
Experimental measurements on an oscillating 70-degree delta wing in subsonic flow [AIAA PAPER 88-2576] p 491 A88-40745
Development of an airfoil of high lift/drag ratio and low moment coefficient for subsonic flow
p 495 A88-40972 Analysis of limit cycle flutter of an airfoil in incompressible flow p 546 A88-41219
Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel [NASA-TM-100529] p 497 N88-22016
Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019
Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model
[PB88-149885] p 528 N88-22038 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241
Langley aerospace test highlights, 1987 [NASA-TM-100595] p 558 N88-22853 Aerofoil testing in a self-streamlining flexible walled wind
tunnel [NASA-CR-4128] p 499 N88-22865
Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunne test force and moment data report
[NASA-CR-177343-VOL-2] p 500 N88-22867 Qualification of a water tunnel for force measurements on aeronautical models p 539 N88-23128
Propfan model wind tunnel aeroelastic research results p 501 N88-23246 WIND TUNNEL WALLS
Velocity profile similarity for viscous flow developmentalong a longitudinally slotted wind-tunnel wall
Highlights of experience with a flexible walled tes section in the NASA Langley 0.3-meter transonic cryogenic
tunnel [AIAA PAPER 88-2036] p 533 A88-37936 Adaptive wall research with two- and three-dimensiona
models in low speed and transonic tunnels [AIAA PAPER 88-2037] p 533 A88-37938 Two-dimensional and three-dimensional adaptation a
the T2 transonic wind tunnel of Onera/Cert [AIAA PAPER 88-2038] p 534 A88-37940 Adaptation of flexible wind tunnel walls for supersonic
flows [AIAA PAPER 88-2039] p 534 A88-37941 The research on adaptive wall wind tunnel in
Northwestern Polytechnical University of China [AIAA PAPER 88-2040] p 534 A88-37942 The use of 2-D adaptive wall test sections for 3-E
flows [AIAA PAPER 88-2041] p 534 A88-37943 Theoretical and experimental analysis of the slotted-wal
flow field in a transonic wind tunnel [SAE PAPER 871757] p 482 A88-38775 Direct assessment of two-dimensional wind-tunne
interference from measurements on two interfaces [AIAA PAPER 88-2539] p 537 A88-40723 CSCM Navier-Stokes thermal/aerodynamic analysis of
hypersonic nozzle flows with slot injection and wal cooling
Flexiwall 3 SO: A second order predictive strategy fo rapid wall adjustment in two-dimensional compressible
flow [NASA-CR-181662] p 498 N88-22016 Porous wind tunnel corrections for counterrotation
propeller testing [NASA-TM-100873] p 498 N88-2201 Investigation of side-wall effects in wind tuning to the control of the cont
supercritical airfoil testing p 498 N88-2224 Aerofoil testing in a self-streamlining flexible walled wind tunnel
[NASA-CR-4128] p 499 N88-2286: Flow quality of NAL two-dimensional transonic win- tunnel. Part 1: Mach number distributions, flow angularitie
and preliminary study of side wall boundary layer suctio [NASA-TT-20209] p 539 N88-2291 WIND TUNNELS
Investigation on the movement of vortex burst position with dynamically changing angle of attack for a schematic with dynamically changing angle of attack for a schematic schem

in a fluctuating wind field p 496 N88-22006 [AD-A190128] Describing the source created by turbulent flow over orifices and louvers p 556 N88-22706 (AD-A190254) WING CAMBER AFTI/F-111 Mission Adaptive Wing flight research program [AIÃA PAPER 88-2118] p 511 A88-38719 Effects of maneuver dynamics on drag polars of the X-29A forward-swept-wing aircraft with automatic wing camber control p 527 A88-38737 [AIAA PAPER 88-2144] WING LOADING Shape sensitivity analysis of wing static aeroelastic characteristics p 516 N88-22031 INASA-TP-28081 WING OSCILLATIONS A study of aeroelastic stability for the model support system of the National Transonic Facility p 533 A88-37936 [AIAA PAPER 88-2033] Experimental measurements on an oscillating 70-degree delta wing in subsonic flow p 491 A88-40745 [AIAA PAPER 88-2576] A comparative study of differing vortex structures arising in unsteady separated flows [AIAA PAPER 88-2582] p 492 A88-40751 Further analysis of wing rock generated by forebody vortices [AIAA PAPER 88-2597] p 494 A88-40768 WING PLANFORMS Experimental investigation of non-planar sheared outboard wing planforms [AIAA PAPER 88-2549] p 489 A88-40731 Experimental and theoretical study of the effects of wing geometry on a supersonic multibody configuration p 494 A88-40766 [AIAA PAPER 88-2510] An integral equation for the linearized supersonic flow ٦t over a wing [AD-A191408] 12 p 501 N88-22875 WING PROFILES Correlation of entrainment and lift enhancement for a two-dimensional propulsive wing p 477 A88-37194 Time-dependent structure in wing-body junction flows p 484 A88-38988 Shape sensitivity analysis of wing static aeroelastic characteristics [NASA-TP-2808] p 516 N88-22031 WING SPAN Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241 WING TIP VORTICES Measurements of turbulent flow behind a wing-body p 484 A88-38987 junction Impingement of orthogonal unsteady vortex structures n on trailing aerodynamic surfaces [AIAA PAPER 88-2580] p 492 A88-40749 Tip vortices of isolated wings and helicopter rotor all hlades p 501 N88-22874 [AD-A191336] WINGLETS el Grid generation and flow analyses for wing/body/winglet configurations [AIAA PAPER 88-2548] p 489 A88-40730 WINGS all Numerical simulation of wings in steady and unsteady ground effects 56 [AIAA PAPER 88-2546] p 488 A88-40728 Experimental and numerical study of the propeller/fixed le wing interaction [AIAA PAPER 88-2571] p 491 A88-40742 18 Modelling the influence of small surface discontinuities in turbulent boundary layers ρn [AIAA PAPER 88-2594] p 546 A88-40759 9 Control of laminar flow around of the wing in free-air th conditions p 495 N88-22004 [AD-A187479] nd Unsteady aerodynamics of a Wortmann FX-63-137 wing in a fluctuating wind field 5 [AD-A190128] p 496 N88-22006 nd A multilifting line method and its application in design es and analysis of nonplanar wing configurations [DFVLR-FB-87-51] p 499 N88-22860 A numerical model of unsteady, subsonic aeroelastic behavior

WIND VELOCITY

Unsteady aerodynamics of a Wortmann FX-63-137 wing

# X

p 499 N88-22862

# **X WING ROTORS**

p 550 N88-23152

p 551 N88-23226

Lewis Structures Technology, 1988. Volume 1: Structural

[NASA-TM-101126]

The RSRA/X-Wing experiment - A status report p 479 A88-37225 [SAE PAPER 872371]

### X-29 AIRCRAFT

Effects of maneuver dynamics on drag polars of the X-29A forward-swept-wing aircraft with automatic wing camber control

[AIAA PAPER 88-2144] Development of a real-time aeroperformance analysis technique for the X-29A advanced technology

demonstrator

p 512 A88-38738 [AIAA PAPER 88-2145] Visualization and anemometry analyses of forced unsteady flows about an X-29 model p 490 A88-40741

[AIAA PAPER 88-2570] XV-15 AIRCRAFT

Using frequency-domain methods to identify XV-15 p 510 A88-37234 [SAE PAPER 872385]

# Υ

Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Modal forced response of propfans in yawed flow p 551 N88-23253

YTTRIUM OXIDES

Corrosion-resistant thermal barrier coatings p 540 A88-38315

Z

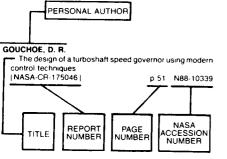
### ZIRCONIUM OXIDES

Corrosion-resistant thermal barrier coatings p 540 A88-38315

in windtunnel WIND TURBINES

[NASA-CP-3003-VOL-1]

### Typical Personal Author Index Listing



Listings in this index are arranged alphabetically by personal author. The title of the document provides the user with a brief description of the subject matter. The report number helps to indicate the type of document listed (e.g., NASA report, translation, NASA contractor report). The page and accession numbers are located beneath and to the right of the title. Under any one author's name the accession numbers are arranged in sequence with the AIAA accession numbers appearing first.

# **ABRAMS, RICHARD**

Skunk Works prototyping [AIAA PAPER 88-2094]

p 473 A88-38710 ACOSTA, A. J.

# Rotordynamic forces on centrifugal pump impellers

p 543 A88-37108

# ACREE, C. W., JR.

Using frequency-domain methods to identify XV-15 aeroelastic modes

### [SAE PAPER 872385]

p 510 A88-37234 ADAMS, M. L.

# Active control and system identification of rotordynamic

p 551 N88-23230 AGARWAL, R. K.

A numerical study of viscous flow in inlets and augmentors [AIAA PAPER 88-0187] p 495 A88-41092

AGGARWAL, A. K.

### Integration of differential GPS with INS for precise

### position, attitude and azimuth determination p 504 A88-37405

# AHUJA, K. K.

### Aeroacoustics of advanced STOVL aircraft plumes [SAE PAPER 872358] p 554 A88-37219 p 554 A88-37219 AIELLO, ROBERT A.

### The composite blade structural analyzer (COBSTRAN) p 525 N88-22390

# ALBERS, JAMES A.

Civil applications of high speed rotorcraft and powered lift aircraft configurations

### [SAE PAPER 872372] ALBERTSON, JULIE A

p 501 A88-37226

Unsteady aerodynamic forces at low airfoil pitching rates [AIAA PAPER 88-2579] p 492 A88-40748

### ALCORN. C. W.

### An experimental investigation of the aerodynamic

characteristics of slanted base ogive cylinders using magnetic suspension technology

### [AIAA PAPER 88-2011] p 481 A88-37919

Visualisation of the flow at the tip of a high speed axial flow turbine rotor

[AD-A189928]

p 546 N88-22300

### ALEXANDER, R. I.

Development of a real-time aeroperformance analysis technique for the X-29A advanced technology

[AIAA PAPER 88-2145] p 512 A88-38738

### ALLGAIER, HANS-JOACHIM

Activities report of Lufthansa

# [ISSN-0176-5086]

p 476 N88-22855 ALTHOFF, SUSAN L.

### Inflow measurement made with a laser velocimeter on a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30

INASA-TM-1005431 p 497 N88-22015 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered planform blades at an advance ratio of 0.15

INASA-TM-1005441 p 499 N88-22863

### ANDRIESEN LARRY R

Powered-lift transport aircraft certification criteria

### [SAE PAPER 872376] ANTOSIEWICZ, M.

Development of an airfoil of high lift/drag ratio and low moment coefficient for subsonic flow

### p 495 A88-40972

p 501 A88-37227

AOKI, TAKAYUKI

Analysis for high compressible supersonic flow in converging nozzle p 500 N88-22869

### HPPJ-8601

APPLEYARD, GEORGE M. Propulsion/aerodynamic integration in ASTOVL combat

ISAE PAPER 8723331 p 508 A88-37202

# ARBUCKLE, P. DOUGLAS

A description of an automated database comparison [NASA-TM-1006091

p 554 N88-23463 ARCHAMBAUD, J. P.

Two-dimensional and three-dimensional adaptation at the T2 transonic wind tunnel of Onera/Cert p 534 A88-37940

### [AIAA PAPER 88-2038] **ARCIDIACONO, PETER**

Rotorcraft technology development at Sikorsky Aircraft

p 476 A88-40561 ARMSTRONG, FRANK W.

Overview of the US/UK ASTOVL program [SAE PAPER 872365] p 473 A88-37238

# ARNDT, N.

Rotordynamic forces on centrifugal pump impellers p 543 A88-37108

# ARNON, ODED

A lightweight innovative Helmet Airborne Display And

### Sight (HADAS)

p 520 A88-41369 ASANO, YOSHIO p 528 A88-40529 Flight testing results of T-2 CCV

ASHWORTH, J. Visualization and anemometry analyses of forced

### unsteady flows about an X-29 model [AIAA PAPER 88-2570] p 490 A88-40741

ASO. SHIGERU

Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves

### p 486 A88-40375 Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer

# AUGUST, RICHARD

Vibration and flutter analysis of the SR-7L large-scale p 551 N88-23254

p 486 A88-40421

### propfan AVNUR, ARIE

A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369

# В

### BACH, RALPH E., JR.

Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model

[AIAA PAPER 88-2134] p 512 A88-38731

### BAILEY, M. L.

Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit

[AIAA PAPER 88-2172] BALSA, T. F.

p 553 A88-38765

Experimental investigation of a spanwise forced mixing layer IAD-A1901361 p 496 N88-22007

### BANDO, TOSHIO

Some topics of ASKA's flight test results and its future nlan ISAE PAPER 872317] p 508 A88-37188

Stability and control augmentation system of 'ASKA' [SAE PAPER 872334] p 527 A88-37203 Flight test of the Japanese USB STOL experimental

[AIAA PAPER 88-2180] p 513 A88-38750

### BANNINK, W. J.

Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence ILR-5181 p 499 N88-22861

# BARATA, J. M. M.

The turbulence characteristics of a single impinging jet through a crossflow p 545 A88-39012

### BARBI, C. Experimental and numerical study of the propeller/fixed

wing interaction [AIAA PAPER 88-2571] p 491 A88-40742

### BARNES, THOMAS B.

Advanced tactical transport needs and design ISAE PAPER 8723371 p 473 A88-37205

### BARTHELEMY, JEAN-FRANCOIS M.

Shape sensitivity analysis of wing static aeroelastic characteristics

p.516 N88-22031

p 523 A88-37215

p 480 A88-37653

p 518 N88-22895

p 475 A88-40558

p 521 N88-22898

# [NASA-TP-2808]

BASSETT, EDWARD W. Osprey's VSLED - Rewriting the maintenance manual

p 474 A88-39325 BATILL. S. M.

Leading edge vortex dynamics on a pitching delta wing I AIAA PAPER 88-25591 p 489 A88-40735

BATTERTON, PETER G. NASA supersonic STOVL propulsion technology

# SAE PAPER 872352]

BAUER, STEVEN X. S. Experimental and theoretical study of the effects of wing geometry on a supersonic multibody configuration
[AIAA PAPER 88-2510] p 494 A88-40766

# BELL, JAMES H.

Contraction design for small low-speed wind tunnels NASA-CR-182747 p 537 N88-22045 BELOTSERKOVSKII, O. M.

# Numerical separation models

BELOTSERKOVSKII, S. M. Computer simulation of turbulent jets and wakes p 544 A88-37661

# **BELTE, DAUMANTS**

Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing

[AD-A190604] p 516 N88-22029 Airworthiness and flight characteristics test of a ski assembly for the UH-60A Black Hawk helicopter

### [AD-A191414] BÈNCZE, D. P.

Calculation of external-internal flow fields mixed-compression inlets p 479 A88-37353 BENDER, GARY L. Preliminary airworthiness evaluation of the UH-60A with

[ETN-88-92275]

Advanced Digital Optical Control System (ADOCS) [AD-A190674] p 516 N88-22030 BENNING, CARL J. 1987 Technical Committee Highlights - The year in

BERARDI, L. Rapid prototyping of complex avionics system

Bifurcations in unsteady aerodynamics-implications for

INASA-TM-1000831

p 497 N88-22014

### BERENS, THOMAS J.

Multiple model parameter adaptive control for in-flight

p 537 N88-22044

BERENS, THOMAS J.

simulation

AD-A1905681

p 519 A88-40518 Improving the reliability of silicon nitride - A case study BERGEN, FRED D. p 540 A88-38316 CANN, GLENN E. Shape sensitivity analysis of wing static aeroelastic Describing the source created by turbulent flow over BOWMAN, C. T. characteristics Turbulent reacting flows and supersonic combustion orifices and louvers p 516 N88-22031 [NASA-TP-2808] p 541 N88-22115 p 556 N88-22706 [AD-A190254] BERRY, SCOTT A. BOYDEN, RICHMOND P. CANNIZZARO, FRANK E. Boundary-layer stability analysis of NLF and LFC A review of Magnetic Suspension and Balance Calculations of three-dimensional flows using the experimental data at subsonic and transonic speeds isenthalpic Euler equations with implicit flux-vector Systems p 483 A88-38925 |SAE PAPER 871859| p 532 A88-37917 [AIAA PAPER 88-2008] splitting [AIAA PAPER 88-2516] BERTELRUD, A. p 493 A88-40762 BRAGG, M. B. A real-time aerodynamic analysis system for use in Experimental measurements on an oscillating 70-degree CANTWELL, ELIZABETH R. fliaht delta wing in subsonic flow [AIAA PAPER 88-2576] Properties of a half-delta wing vortex p 491 A88-40745 | AIAA PAPER 88-2128 | p 512 A88-38728 p 483 A88-38985 BEVILAQUA, PAUL M. BRAHNEY, JAMES H. CAPONE, FRANCIS J. p 510 A88-38352 Advances in ejector thrust augmentation Almost all composite helicopter A flow-transfer device with nonmetallic diaphragms for p 522 A88-37191 p 510 A88-38353 |SAE PAPER 872322| Radial tires for aircraft? propulsion wind tunnel models BRANDON, J. M. BILEKA, B. D. [AIAA PAPER 88-2048] p 534 A88-37945 Experimental measurements on an oscillating 70-degree Thermal state of a turbofan rotor p 545 A88-40317 CAREL, OLIVIER delta wing in subsonic flow BILL, ROBERT C. Implementation of aeronautical mobile satellite services p 491 A88-40745 An overview of rotorcraft propulsion research at Lewis [AIAA PAPER 88-2576] p 506 A88-40519 (AMSSs) p 524 A88-40554 BRAZA, RUDY M. Research Center CARLIN, G. J., JR. Experimental comparison of lightning simulation BILLET, M. L. Experimental and analytical aerodynamics of an techniques to CV-580 airborne lightning strike Experimental investigation of a jet impinging on a ground advanced rotor in hover measurements plane in the presence of a cross flow n 488 A88-40717 [AIAA PAPER 88-2530] p 552 N88-22496 [AD-A190576] ISAE PAPER 8723261 p 478 A88-37195 CARPENTIER, JEAN BRENNEN, C. E. Aerospace progress and research - The fortieth anniversary of ONERA p 557 A88-40548 BINDON, J. Rotordynamic forces on centrifugal pump impellers Visualisation of the flow at the tip of a high speed axial p 543 A88-37108 flow turbine rotor CARROLL, B. F. BRENNER, MATS A. p 546 N88-22300 IAD-A1899281 Numerical and experimental investigation of multiple GPS integrity monitoring for commercial applications BINEGAR, SCOTT A. shock wave/turbulent boundary layer interactions in a p 505 A88-37412 using an IRS as a reference The use of a computer model to investigate design rectangular duct BRISTEAU, M. O. compatibility between the QF-4 aircraft and the AD-A190772] p 547 N88-22320 On the use of subcycling for solving the compressible AQM-127A CARRUTHERS, DAVE Navier-Stokes equations by operator-splitting and finite p 512 A88-38736 IAIAA PAPER 88-21431 p 495 A88-41269 Gas turbines challenge ceramic technology lement methods p 540 A88-37430 BIPPES, H. BRITCHER, C. P. Experimental investigation of topological structures in An experimental investigation of the aerodynamic CARTER, DENNIS L. p 486 A88-39970 three-dimensional separated flow characteristics of slanted base ogive cylinders using The integration of wind tunnel and water tunnel results BIRRENBACH, REINHOLD for a new in-flight simulator configuration magnetic suspension technology p 514 A88-39415 p 536 A88-39525 Dornier 328 taking shape p 481 A88-37919 (AIAA PAPER 88-2045) [AIAA PAPER 88-2011] BITTER, PETER Testing new aircraft - Is there an R&M challenge?
[AIAA PAPER 88-2182] p 474 A88-3 BRITCHER, COLIN P. Progress towards extreme attitude testing with Magnetic Information systems for quality. Experience at the p 474 A88-38752 Nerviano Aeritalia plant. Avionic systems and equipment Suspension and Balance Systems BLACK, H. P. p 532 A88-37920 [AIAA PAPER 88-2012] The AEDC 1-foot transonic wind tunnel - A useful p 557 N88-22821 IETN-88-922741 BROCARD, Y. research and development facility CASEY, JEAN M. Qualification of a water tunnel for force measurements p 531 A88-37912 [AIAA PAPER 88-2001] A fully integrated GPS/Doppler/inertial navigation p 539 N88-23128 on aeronautical models BLAHA, BERNARD J. p 504 A88-37400 BROOKS, CUYLER W., JR. system NASA supersonic STOVL propulsion technology CASON, RANDALL W. Modifications to the Langley 8-foot transonic pressure Preliminary airworthiness evaluation of the UH-60A program tunnel for the laminar flow control experiment SAF PAPER 8723521 p 523 A88-37215 p 538 N88-22047 equipped with the XM-139 VOLCANO mine dispensing INASA-TM-40321 BLAKE, BRUCE B. BROWN, CLINTON E. Research and Development at Boeing Helicopters p 516 N88-22029 An experimental study to determine the flow and the [ÁD-A190604] p 476 A88-40560 Airworthiness and flight characteristics test of a ski subsonic static and dynamic stability characteristics of **BLAUROCK, JOERG** assembly for the UH-60A Black Hawk helicopter aircraft operating at high angles-of-attack Measurements of the time dependent velocity field p 518 N88-23129 p 518 N88-22895 (AD-A1914141 surrounding a model propeller in uniform water flow CATHEY, JIMMIE J. BROWN, DERRELL L. p 550 N88-23155 VSTOL design implications for tactical transports Control of an aircraft electric fuel pump drive BLISS, DONALD B. p 473 A88-37206 p 524 A88-39133 [SAE PAPER 872338] Reduced order models for nonlinear aerodynamics CAUGHEY, T. K. BROWN, JAMES M. p 501 N88-23248 The Canadian Marconi Company GPS receiver - Its Rotordynamic forces on centrifugal pump impellers BLUM. T. p 503 A88-37394 p 543 A88-37108 development, test, and future PNS calculations of hypersonic transitional flow over CAYSE, R. W. BRYKINA, I. G. Aerodynamic lag of a close-coupled canard aircraft cones Analytical study of friction and heat transfer in the vicinity p 490 A88-40738 [AIAA PAPER 88-2565] of a three-dimensional critical point at low and moderate model at Mach 0.3 to 1.6 BOBAK, MICHAEL T. p 481 A88-37933 p 483 A88-38847 Reynolds numbers [AIAA PAPER 88-2030] Estimation of turbulence effects on sound propagation CEBECI, TUNCER BUBNOV, ALEKSANDR VLADIMIROVICH p 555 A88-39712 from low flying aircraft Separation and reattachment near theleading edge of Flight fatigue testing of helicopters p 486 A88-39967 BOBBITT, P. J. p 510 A88-37703 a thin wing Theoretical investigations, and correlative studies for Oscillating airfoils: Achievements and conjectures BUCHANAN, T. D. NLF, HLFC, and LFC swept wings at subsonic, transonic p 496 N88-22008 (AD-A190490) Aerodynamic lag of a close-coupled canard aircraft model at Mach 0.3 to 1.6 and supersonic speeds CHAKRAVARTHY, SUKUMAR R. p 483 A88-38950 ISAE PAPER 871861] Transonic Euler calculations of a wi configuration using a high-accuracy TVD scheme of a wing-body p 481 A88-37933 [AIAA PAPER 88-2030] BOCKMAIR, M. A millimeter-wave low-range radar altimeter for BUERGEL, RALF p 488 A88-40729 [AIAA PAPER 88-2547] helicopter applications - Experimental results Evaluation of ceramic thermal barrier coatings for gas CHAMBERS, JOSEPH R. p 519 A88-39496 turbine engine components Use of dynamically scaled models for studies of the p 543 N88-22998 [FTN-88-91947] BOECK, J. high-angle-of-attack behavior of airplanes A real-time aerodynamic analysis system for use in BURITZ, ROBERT S. p 535 A88-38692 Advanced capacitor development flight CHAMIS CHRISTOS C. p 512 A88-38728 p 546 N88-22276 [AIAA PAPER 88-2128] [AD-A189985] for Computational structural mechanics engine p 525 N88-22399 BOERSTOEL, J. W. BURKS, JOHN S. Trends in Computational Fluid Dynamics (CFD) for p 475 A88-40552 Rotorcraft research at NASA CHANA, WILLIAM F. aeronautical 3D steady applications: The Dutch situation Design, construction and flight testing the Spirit of St. BUTLER, R. W. p 498 N88-22017 INLR-MP-86074-U1 Study on needs for a magnetic suspension system BOGDONOFF, S. M. [AIAA PAPER 88-2187] p 557 A88-38755 operating with a transonic wind tunnel Observation of three-dimensional 'separation' in shock p 533 A88-37922 [AIAA PAPER 88-2014] CHAPMAN, GARY T. wave turbulent boundary layer interactions An overview of hypersonic aerothermodynamics BUYSKIKH, K. P. p 486 A88-39952 p 495 A88-41270

Model study of thermal stresses in gas-turbine blades

with protective coating

Mode 2 fracture mechanics

BUZZARD, ROBERT J.

p 542 N88-22989

p 548 N88-22418

BOSZKO, P. J.

BOWEN, LESLIE J.

chamber

Water flow visualisation of a ramrocket combustion

p 549 N88-23138

CAMUS, PAUL

Navigation and performance computer

program

BONNEMA, KENNETH L.

[AIAA PAPER 88-2118]

AFTI/F-111 Mission Adaptive Wing flight research

p 511 A88-38719

CHATTOPADHYAY, ADIT!

Minimum weight design of rotorcraft blades with multiple frequency and stress constraints

[NASA-TM-100569] p 517 N88-22892

CHAWLA, M. D.

Wind tunnel investigation of wing-in-ground effects AIAA PAPER 88-2527 p 488 A88-40716 CHEN, ALLEN W.

Grid generation and flow analyses for wing/body/winglet

configurations I AIAA PAPER 88-2548 J p 489 A88-40730

CHEN, HAI-CHOW

Grid generation and flow analyses for wing/body/winglet configurations

[AIAA PAPER 88-2548] n 489 A88-40730

CHEN, NANQIAN

The characteristics of asymmetric vortices and side forces on a sharp-nosed body with wing and vertical tail p 482 A88-38188

CHEN, OISHUN

Aircraft flight dynamics research in past decade p 518 N88-23031

CHENEY, HAROLD K.

A flexible computer program for aircraft flight test [AIAA PAPER 88-2125] p 553 A88-38725

A new method to confirm category III autoland performance [AIAA PAPER 88-2126]

p 505 A88-38726 CHERANOVSKIY, O. R.

Control of laminar flow around of the wing in free-air conditions

AD-A1874791 p 495 N88-22004 CHEUNG, C. W.

Wind tunnel interference on unsteady two-dimensional perofoil motions in low speed flows p 535 A88-38169

CHEZLEPRETRE, B. Qualification of a water tunnel for force measurements

on aeronautical models p 539 N88-23128 CHILDRESS, OTIS S., JR. The NASA/AHS Rotorcraft Noise Reduction Program

p 475 A88-40553 CHILDS, ROBERT E.

Turbulence and fluid/acoustic interaction in impinging

[SAE PAPER 872345] p 478 A88-37211 CHILES, HARRY R.

Techniques used in the F-14 variable-sweep transition flight experiment

IAIAA PAPER 88-2110] p 513 A88-38762 CHOPRA, INDERJIT

Assessment of transient testing techniques for rotor stability testing AIAA PAPER 88-2401 p 546 A88-40871

CHU. WING-FONG

Corrosion-resistant thermal barrier coatings p 540 A88-38315

CHUANG, S.

Scale model acoustic testing of counterrotating fans [AIAA PAPER 88-2057] p 523 A88-37947 CHUECH S G

The structure of sonic underexpanded turbulent air jets in still air IAD-A1908561 p 500 N88-22870

CHYU, W. J. Calculation of external-internal flow fields for

mixed-compression inlets p 479 A88-37353 CIMBALA, J. M.

Experimental investigation of a jet impinging on a ground plane in the presence of a cross flow

[SAE PAPER 872326] p 478 A88-37195 CLEARY, JOSEPH W.

Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601

COCKRELL, D. J. Measurements of aerodynamic forces on unsteadily

moving bluff parachute canopies p 549 N88-23137 CODDING, WILLIAM H.

CSCM Navier-Stokes thermal/aerodynamic analysis of hypersonic nozzle flows with slot injection and wall cooling

[AIAA PAPER 88-2587] p 493 A88-40756 COLE, J. E., III

Structureborne noise measurements on a small twin-engine aircraft

[NASA-CR-4137] p 556 N88-23545 COLE, JEFFREY L

Development and qualification of S-76B category 'A' takeoff procedure featuring variable CDP and V2 speeds [AIAA PAPER 88-2127] p 511 A88-38727

COLOMBINI, R. Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment

[ETN-88-92274] p 557 N88-22821 COMPERINI, ROBERT

Development of an interactive real-time graphics system for the display of vehicle space positioning

[AIAA PAPER 88-2167] p 536 A88-38744 COOK, ROBERT F.

Soft-ground aircraft arresting systems

[AD-A190838] p 539 N88-22912

COONS, LEE

STOVL RCS effects on propulsion system design [SAE PAPER 872349] p 522 A88-37214

COPELAND, H. W., JR.

The high technology test bed program - An overview **ISAE PAPER 8723121** p 507 A88-37183

CORSIGLIA, VICTOR R.

Aerodynamic flow quality and acoustic characteristics of the 40- by 80-foot test section circuit of the National Full-Scale Aerodynamic Complex

[SAE PAPER 872328] p 530 A88-37197 COURVILLE, G. E.

Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046

COWLES, LISA J.

High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory [AD-A189871] p 496 N88-22005

COX. ARTHUR

Display system optics; Proceedings of the Meeting, Orlando, FL, May 21, 22, 1987 p 520 A88-41361

Computerized life and reliability modelling for turboprop transmissions p 551 N88-23220

[NASA-TM-100918]

COY, JOHN J. An overview of rotorcraft propulsion research at Lewis

Research Center p 524 A88-40554

CRAWFORD, M. L.

EMR (Electromagnetic Radiation) test facilities evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York IPR88-1788271 p 538 N88-22048

CRONKHITE JAMES D.

Special report on Bell ACAP full-scale aircraft crash

[SAE PAPER 872362] p 509 A88-37223

CUI, TAORUI

Numerical calculations of a class of optimal flight trajectories p 553 A88-38178

D

DADONE, L.

Experimental and analytical aerodynamics of an advanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717

DAGENHART, J. RAY

Boundary-layer stability analysis of NLF and LFC experimental data at subsonic and transonic speeds [SAE PAPER 871859] p 483 A88-38925 ISAE PAPER 871859]

DALLMANN, UWE

Theoretical investigation of secondary instability of three-dimensional boundary-layer flows with application to the DFVLR-F5 model wing

[DFVLR-FB-87-44] p 547 N88-22330

DARIPA, PRABIR On inverse airfoit design

AIAA PAPER 88-2573] p 495 A88-41048

DAVIS. GREGORY E.

Diagnostic design requirements for integrated avionic subsystems [AIAA PAPER 88-2171] p 553 A88-38746

DEESE, J. E. A numerical study of viscous flow in inlets and

augmentors [AIAA PAPER 88-0187] p 495 A88-41092

DELEEUW, J. H.

The application of linear maximum likelihood estimation of aerodynamic derivatives for the Bell-205 and Bell-206 IAD-A1912791 p 518 N88-22894

DELFRATE, JOHN

Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 DEMMEL, JOHANN

Standardized ice accretion thickness as a function of cloud physics parameters [ESA-TT-1080] p 553 N88-23346

DETLEFSEN, J.

A millimeter-wave low-range radar altimeter for

helicopter applications - Experimental results p 519 A88-39496 DETLEFSEN, WOLFGANG

Taxiway safety using mode S SSR

p 519 A88-39495 DEVENPORT, WILLIAM J.

Time-dependent structure in wing-body junction flows p 484 A88-38988

DEVEREAUX, P. A. Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel

test pressure data report INASA-CR-177343-VOL-11 p 500 N88-22866

DIACHENKO, A. M. Thermal state of a turbofan rotor p 545 A88-40317 DICKMANNS, F. D.

Computer vision for flight vehicles

p 527 A88-39485 DILLEY, ARTHUR D.

Computational validation of a parabolized Navier-Stokes solver on a sharp-nose cone at hypersonic speeds IAIAA PAPER 88-25661 p 490 A88-40739

DILLON, JAMES L. Unexpected/expected results from the Langley 20-Inch

Supersonic Wind Tunnel during initial checkout (AIAA PAPER 88-1999) p 531 A88-37911

DOBRONSKI, S. J. Joint Tactical Information Distribution System (JTIDS)

class 2 terminal flight test [AIAA PAPER 88-2119 p 505 A88-38720

DONALDSON, JOSEPH C. On hypersonic transition testing and prediction

[AIAA PAPER 88-2007] p 532 A88-37916 DONE, G. T. S.

The use of smooth bending moment modes in helicopter rotor blade vibration studies

DONOVAN, J. F. Detection of large-scale organized motions in a turbulent boundary layer

p 484 A88-39023 DOTY, DALE A. Flight testing at the West Coast Offshore Operating

Area [AIAA PAPER 88-2150] p 536 A88-38740

DOWELL, EARL H. Reduced order models for nonlinear aerodynamics

p 501 N88-23248 DOWNING, DAVID R. Analysis of a range estimator which uses MLS angle

measurements INASA-CR-1828961 p 507 N88-22884

DOWNING, L. E.

Analytical sensor redundancy assessment

[NASA-CR-182892] p 521 N88-22901

DRESS, DAVID A. Drag measurements on a body of revolution in Langley's

13-inch Magnetic Suspension and Balance System [AIAA PAPER 88-2010] p 532 A88-37918 DULKE, MICHAEL F.

Heat transfer modeling of jet vane Thrust Vector Control (TVC) systems

IAD-A1901061 p 524 N88-22034 DURAO, D. F. G.

The turbulence characteristics of a single impinging jet p 545 A88-39012 through a crossflow

DURSTON, DONALD A. Wave drag and high-speed performance of supersonic

STOVL fighter configurations [SAE PAPER 872311] p 479 A88-37235 DUTTON, J. C.

Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a

rectangular duct IAD-A1907721 p 547 N88-22320

Computer simulation of turbulent jets and wakes

DVORAK, A. V.

DZHAVADOV, G. G. Information properties complex angular-coordinate estimates p 545 A88-38448

DZYKOVICH, I. YA.

Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990

E

EBATO, NOBUO

Current trend of digital map processing

p 506 A88-40533

p 544 A88-37661

EDENBOROUGH, H. KIPLING

Aerodynamic flow quality and acoustic characteristics of the 40- by 80-foot test section circuit of the National Full-Scale Aerodynamic Complex **ISAE PAPER 8723281** p 530 A88-37197

EDWARDS, F. G.

Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397

Bibliography of icing on aircraft (status 1987)

[DFVLR-MIT-87-18] p 502 N88-22876

**FUCHS, WERNER** 

GLADEN, K. S.

p 512 A88-38735

p 540 A88-37429

Development of a control system for an injector powered transonic wind tunnel [AIAA PAPER 88-2063] p 535 A88-37950

EDWARDS, L. C.
Wind tunnel investigation of wing-in-ground effects
[AIAA PAPER 88-2527] p 488 A88-40716

EKVALL, JOHN C.	p 400 700-407 10	FANTUZI, ANGELO		FUJII, KOZO	
Elevated-temperature Al alloys for a	aircraft structure	Fog persistence above some a	irports of the north-Italian	Navier Stokes computation of	
	p 541 A88-40486	plains	p 552 A88-38372	wings with spanwise leading edg [AIAA PAPER 88-2558]	p 489 A88-40734
ELENA, MAX		FARBRIDGE, J. E. A review of the de Havilland aug	amentor-wing powered-lift	A method to increase the a	
Experimental study of a supersonic	turbulent boundary	concept and its future applicatio	ns	simulations	toodiady or vortical trott
layer using a laser Doppler anemome	ter	[SAE PAPER 872313]	p 507 A88-37184	[AIAA PAPER 88-2562]	p 490 A88-40736
	p 485 A88-39623	FARLEY, HAROLD C.		FUJIWARA, TOSHI	
ELFSTROM, G. M. Optimum porosity for an inclined-	halo transanic test	Skunk Works prototyping		Improvements on accuracy and	l efficiency for calculation
section wall treated for edgetone nois	e reduction	[AIAA PAPER 88-2094]	p 473 A88-38710	of transonic viscous flow around	an airfoil
	p 531 A88-37914	FAVIER, D.	I of the assembles /fixed		p 482 A88-38303
ELHADY, NABIL M.	p 007 1100 411011	Experimental and numerical st	tudy of the propeller/fixed	FULLER, C. R.	
Nonlinear wave interactions in swep	ot wing flows	wing interaction [AIAA PAPER 88-2571]	p 491 A88-40742	Active control of sound fields	
[NASA-CR-4142]	p 550 N88-23160	FECHTER, JUDIE	<b>p</b> 101 / 102 / 101	vibrational inputs	p 556 A88-39725
ELLIOTT, J. W.		Keys to a successful flight tes	st	FULLER, CHRIS R.  Mechanisms of active control for	or naica innida a vibratina
Advancing-side directivity and		[AIAÁ PAPER 88-2174]	p 519 A88-38766		p 555 A88-39722
interactions of model rotor blade-vort	ex interaction noise	FENG, GANG		cylinder	p 333 A00-03722
1	p 556 N88-22710	Control law design of a CCV a	airplane	FUNG, YT. Microprocessor control of	high-speed wind tunnel
ELLIOTT, JOE W.	4		p 527 A88-38192	stagnation pressure	g., -p
Inflow measurement made with a la	aser velocimeter on	FENNO, CHARLES C., JR. Unsteady viscous-inviscid inte	oraction procedures for	[AIAA PAPER 88-2062]	p 535 A88-37949
a helicopter model in forward flight. Vo planform blades at an advance ratio	nume 3; nectangular	transonic airfoils using Cartesiar		FUNK, MATHEW	
[NASA-TM-100543]	p 497 N88-22015	[AIAA PAPER 88-2591]	p 493 A88-40757	Thrust efficiency of powered li	
Inflow measurements made with a I		FERNANDO, E. M.		[SAE PAPER 872327]	p 522 A88-37196
a helicopter model in forward flight.	Volume 4: Tapered	Detection of large-scale organ	ized motions in a turbulent	FYLES, PETER A.	
planform blades at an advance ratio	of 0.15	boundary layer	p 484 A88-39023	The effects of torque respon	
[NASA-TM-100544]	p 499 N88-22863	FERRIS, J. C.		rotorcraft vertical axis handling of	
ELLIS, JOHN C., II		Theoretical investigations, ar	nd correlative studies for	[AD-A189873]	p 515 N88-22023
Noise assessment of unsuppresse	ed TF-34-GE-100A	NLF, HLFC, and LFC swept wir	ngs at subsonic, transonic		
engine at Warfield ANG, Baltimore, M	laryland	and supersonic speeds (SAE PAPER 871861)	p 483 A88-38950	G	
(AD-A189966)	p 556 N88-22702	FIDDES, S. P.	p 400 /100 00000	<del>-</del>	
ENGLAR, ROBERT J.		Prediction of vortex lift of no	on-planar wings by the	GALANT, S.	
The application of circulation	control pneumatic	leading-edge suction analogy	p 485 A88-39279	Development of a variational m	ethod for chemical kinetic
technology to powered-lift STOL aircr	p 508 A88-37204	FISCHER, HANS WERNER		sensitivity analysis	p 541 A88-38490
[SAE PAPER 872335]	p 500 A00-57204	Basic design studies for the r	ealization of liquid crystal	GAMO, MINORU	
ENGLUND, DAVID R. Research sensors	p 548 N88-22430	display systems in aircraft	- 504 Ngg 22000	Aircraft observation of the spe	
ENZINGER, FRANZ J.	P 545 1155 EE 155	[VA-87-001]	p 521 N88-22900	of the water vapor transfer in the layer	p 552 A88-39508
Program review of European Fighte	er Aircraft	FISCHER, THOMAS M.  Theoretical investigation of	of secondary instability of	GAMON, M. A.	p 502 760 00000
[AIAA PAPER 88-2120]	p 511 A88-38721	three-dimensional boundary-laye	er flows with application to	Study of powered-lift aircraft u	using jump struts
EPPEL, JOSEPH C.		the DFVLR-F5 model wing		[AIAA PAPER 88-2179]	p 513 A88-38749
Quiet Short-Haul Research Aircraft	- A summary of flight	[DFVLR-FB-87-44]	p 547 N88-22330	GÀNZER, U.	
research since 1981	p 508 A88-37186	FLEETER, SANFORD		Adaptation of flexible wind tu	innel walls for supersonic
[SAE PAPER 872315]	p 508 A88-37 100	Research as part of the Air	Force in aero propulsion	flows	501 100 07014
ERICKSON, GARY E.  Water facilities in retrospect	and prospect: An	technology (AFRAPT) program	505 NOO 00000	[AIAA PAPER 88-2039]	p 534 A88-37941
illuminating tool for vehicle design	p 539 N88-23126	[AD-A190336]	p 525 N88-22036	GAO, CHAO Investigation of side-wall ef	facts in wind tunnel with
ERICSSON, L. E.	F	FLUK, HAROLD  Landing surface characteris	stice unique to V/STOI	supercritical airfoil testing	p 498 N88-22241
Review of transition effects on the	problem of dynamic	aircraft	stics dilique to \$70102	GARLAND, D. B.	p 100 1100 III
simulation		[SAE PAPER 872310]	p 530 A88-37182	Development of lift ejectors for	or STOVL combat aircraft
[AIAA PAPER 88-2004]	p 532 A88-37915	FORSETH, D. C.	·	(SAE PAPER 872324)	p 522 A88-37193
Fluid mechanics of dynamic stall	p 485 A88-39511	GPS phase III multi-channel	user equipment	GAROUTTE, STANLEY K.	
concepts  Fluid mechanics of dynamic stall.			p 503 A88-37378	Flight testing at the West C	oast Offshore Operating
scale characteristics	p 485 A88-39512	FOSTER, JOHN D.	and for transition and	Area	p 536 A88-38740
Further analysis of wing rock ger		Integrated control and display vertical flight on the NASA V	//STOL Beearch Aircraft	[AIAA PAPER 88-2150] GARTENBERG, EHUD	p 550 A66-56740
vortices	, ,	(VSRA)	75TOL Research Ancian	Aerodynamic investigation by	infrareit imaging
[AIAA PAPER 88-2597]	p 494 A88-40768	[SAE PAPER 872329]	p 526 A88-37198	[AIAA PAPER 88-2523]	p 545 A88-40713
ERIKSSON, LARS-ERIK		FRADENBURGH, EVAN A.	P	GASTON, G. G.	r
Flow solution on a dual-block grid		1987 Technical Committee	Highlights - The year in	A highly monitored AV-8B Ha	ırrier II digital flight control
G: Lutin of the control flow in radio	p 479 A88-37355	review	p 475 A88-40558	system	
Simulation of transonic flow in radi	p 480 A88-37356	FRANKE, M. E.		(SAE PAPER 872332)	p 527 A88-37201
ESCH, PETER	F .00 7.00 07000	Wind tunnel investigation	of wing-in-ground effects	GESSOW, ALFRED	collongs at the University
Large-scale model for experim	ental wind tunnel	[AIAA PAPER 88-2527]	p 488 A88-40716	The Rotorcraft Center of Ex- of Maryland	p 475 A88-40556
investigations	p 531 A88-37298	FRANKLIN, JAMES A.		GHAFFARI, FARHAD	p -7.5 7100 -10000
ESCHENBACH, RALPH		Integrated control and display vertical flight on the NASA V	//STOL Research Aircraft	An analytical method for th	e ditching analysis of an
Differential GPS with a sequencing			75TOL Research Allician	airborne vehicle	• ,
	p 505 A88-37406	(VSRA) (SAE PAPER 872329)	p 526 A88-37198	[AIAA PAPER 88-2521]	p 514 A88-40711
EVERHART, JOEL L.	e flew dayalanmant	FRANZ, R.	<b>P 020</b>	GHOSN, LOUIS	
Velocity profile similarity for viscou along a longitudinally slotted wind-tur	as now development	Rotordynamic forces on cent	trifugal pump impellers	Mode 2 fracture mechanics	p 548 N88-22418
[AIAA PAPER 88-2029]	p 481 A88-37932	110.010,710	p 543 A88-37108	GIBBAR, K. W.	II disital flight agates
Theoretical and experimental analysis		FRATELLO, G.		A highly monitored AV-8B Ha	arrier ii digital filgnt contro
flow field in a transonic wind tunnel		Experimental and numerical s	study of the propeller/fixed	system [SAE PAPER 872332]	p 527 A88-37201
[SAE PAPER 871757]	p 482 A88-38775	wing interaction		GIESKE, J. H.	p 02. 7.00 0.20.
EYDALEINE, GENEVIEVE		[AIAA PAPER 88-2571]	p 491 A88-40742	Ultrasonic Time-Of-Flight	Diffraction (TOFD)
Navigation by satellite - The next s	step for civil aviation	FRAZIER, DAVID E.	4.000	measurements of crack depths i	
	p 506 A88-39375	T-33 aircraft demonstration		of a high velocity research gun	
_		navigation	p 504 A88-37403	[DE88-006644]	p 538 N88-22907
F		FRENCH, EDWARD	of the USAE/ESMC GDS	GIORGI, N.	
		Results of dynamic testing user equipment aboard the ra	unde tracking shine LISNS	Rapid prototyping of co	mpiex avionics system
FAETH, G. M.		Observation Island and USNS	Redstone	architectures [ETN-88-92275]	p 521 N88-22898
The structure of sonic underexpan	ded turbulent air jets	Coortain. India and Corto	p 503 A88-37385	GLADDEN, HERBERT J.	p 52. 1400 E2000
in still air	p 500 N88-22870	FRENCH, K. E.		Review and assessment of	the HOST turbine hear
[AD-A190856] FALARSKI, MICHAEL D.	P 300 1400-22010	Flight test experience wi	th an RPV emergency	transfer program	p 526 N88-22431
, representation of the pro-				OLABEN K O	

(parachute) recovery system [AIAA PAPER 88-2139]

Kryptonite they are not

FRISCH, BRUCE

Aircraft flight dynamics research in past decade reviewed

FAN, LIQIN

[SAE PAPER 872328]

Aerodynamic flow quality and acoustic characteristics of the 40- by 80-foot test section circuit of the National Full-Scale Aerodynamic Complex

p 530 A88-37197

GLASS.	CHRISTOPHE	3 F

Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5

[NASA-TP-2804] GLEZER, A.

p 547 N88-22325

Experimental investigation of a spanwise forced mixing

IAD-A1901361 GLOWINSKI, R.

p 496 N88-22007

On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269

GODDARD, DANIEL G.

Application of eigenstructure assignment techniques in the design of a longitudinal flight control system p 528 N88-22039

GOETTSCHING I

Designs of profiles for cascades

[NASA-TT-20161]

p 547 N88-22326

GOLDSCHMIED, FARIO R

On a least-energy hypothesis for the wake of axisymmetric bodies with turbulent separation - Pressure-distribution prediction [AIAA PAPER 88-2513] p 487 A88-40705

GOODMAN, ALEX

An experimental study to determine the flow and the subsonic static and dynamic stability characteristics of

aircraft operating at high angles-of-attack p 518 N88-23129 GOODSON, DAVID L.

The use of a computer model to investigate design compatibility between the QF-4 aircraft and the [AIAA PAPER 88-2143]

GOODYER, M. J.

p 512 A88-38736

Adaptive wall research with two- and three-dimensional models in low speed and transonic tunnels

[AIAA PAPER 88-2037] p 533 A88-37939 Flexiwall 3 SO: A second order predictive strategy for rapid wall adjustment in two-dimensional compressible flow

[NASA-CR-181662]

p 498 N88-22018

p 483 A88-38950

GORADIA, S. H.
Theoretical investigations, and correlative studies for NLF, HLFC, and LFC swept wings at subsonic, transonic and supersonic speeds [SAE PAPER 871861]

GORADIA, SURESH H.

Velocity profile similarity for viscous flow development along a longitudinally slotted wind-tunnel wall

[AIAA PAPER 88-2029] p 481 A88-37932 GRABIN, V. V.

Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990

GRASWALD, S. Computation of cascade flow using a finite-flux-element method

p 485 A88-39488 GRAY, D. E.

Features and capabilities of the DOD standard GPS receivers for aircraft and seaborne applications p 503 A88-37379

GRECHANYUK, N. I.

Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990 condensation rate
GRIMSHAW, JEFFREY D.
Kalman filter residual expert system

p 529 N88-22041

GROEN, DAVID S.

STOVL acoustic fatigue technologies [SAE PAPER 872360] p

p 555 A88-37221 GROENIG, H.

Short duration flow establishment on a profile in a Water-Ludwieg-Tunnel p 549 N88-23134

GROUSET, D. Development of a variational method for chemical kinetic

sensitivity analysis p 541 A88-38490 **GUAN. YANSHEN** 

Linear dynamics of supersonic inlet

p 482 A88-38186

GUDERLEY, KARL G. An integral equation for the linearized supersonic flow

over a wing [AD-A191408] p 501 N88-22875

**GUNNINK, J. W.** 

Design studies of primary aircraft structures in ARALL laminates

[LR-520] GUPTA, K. K.

Development of a block Lanczos algorithm for free vibration analysis of spinning structures p 545 A88-40117

GUSTAVSSON, ANDERS I.

In-service measurements of SAAB SF-340 landing gear

[FFA-TN-1987-48]

p 516 N88-22032

p 517 N88-22888

HAMMONS, KEVIN R.

The PC/AT compatible computer as a mission control center display processor at Ames-Dryden Flight Research

[AIAA PAPER 88-2168] p 536 A88-38745 Real-time flight test data distribution and display

[NASA-TM-100424] HANCOCK, G. J.

Wind tunnel interference on unsteady two-dimensional aerofoil motions in low speed flows p 535 A88-38169

HANCOCK, THOMAS P.

Using GPS to enhance the DT&E ranges [AIAA PAPER 88-2098] p 536 p 536 A88-38713

HANSON, R. K.

Turbulent reacting flows and supersonic combustion [AD-A189690]

HARDY, B. C.

Prediction of vortex lift of non-planar wings by the leading-edge suction analogy p 485 A88-39279

HARDY, GORDON H.

Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft [SAE PAPER 872316]

HARNEY, CONSTANCE D.

Development of an integrated set of research facilities for the support of research flight test

[AIAA PAPER 88-2096] p 535 A88-38712

HARRIS, CHARLES D.

Modifications to the Langley 8-foot transonic pressure tunnel for the laminar flow control experiment [NASA-TM-4032] p 538 N88-22047

HARTMAN, RANDOLPH G.

An integrated GPS/IRS design approach p 504 A88-37404

HARTMANN, RUDOLF

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ISPIE-7781 p 520 A88-41361 Suppressing display cockpit reflections

p 515 A88-41364

p 508 A88-37187

HARVEY, H. M.

Lift engines - Applied history [SAE PAPER 872347]

p 522 A88-37213 HARVEY, W. D.

Theoretical investigations, and correlative studies for NLF, HLFC, and LFC swept wings at subsonic, transonic and supersonic speeds

[SAE PAPER 871861] p 483 A88-38950 HARWOOD, R. J.

Measurements of aerodynamic forces on unsteadily moving bluff parachute canopies p 549 N88-23137

Vehicles and aircraft on floating ice

p 536 A88-40066 HASSAN, H. A.

Unsteady viscous-inviscid interaction procedures for transonic airfoils using Cartesian grids [AIAA PAPER 88-2591] p 493 A88-40757

HATEMATA NORORII Structure and equipments of the T-2 CCV aircraft

p 514 A88-40530 HAYAFUJI, HIROSHI

Structure and equipments of the T-2 CCV aircraft p 514 A88-40530

HAYASHI, MASANORI

Heat flux on the surface of a wedge in Mach reflection

and regular reflection of shock waves p 486 A88-40375

Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421

HAYASHI, YOSHIO

Some topics of ASKA's flight test results and its future

[SAE PAPER 872317] HAYEK, SABIH I.

p 508 A88-37188

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HE, JIA JU

The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China

p 555 A88-39701

[AIAA PAPER 88-2040] p 534 A88-37942 HÈAPHY, B.

A real-time aerodynamic analysis system for use in fliaht [AIAA PAPER 88-2128] p 512 A88-38728

HEGARTY, D. M.

Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397

HEGER, C. E.

A digital P-code GPS reciever and its applications to embedded systems p 503 A88-37393

HEITOR, M. V.

The turbulence characteristics of a single impinging jet through a crossflow HEPNER, TIMOTHY E. p 545 A88-39012

Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024]

p 544 A88-37929 HERGT, P.

Cascade lift ratios for radial and semiaxial rotating cascades p 543 A88-37110 HERNANDEZ, E. G.

Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 p 513 A88-38748 HICKS, J. W.

Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator

AIAA PAPER 88-21451

p 512 A88-38738

p 474 A88-38723

HICKS, JOHN W. Effects of maneuver dynamics on drag polars of the X-29A forward-swept-wing aircraft with automatic wing camber control

[AIAA PAPER 88-2144] HIGGS, JOHN T.

p 527 A88-38737

Air Force One replacement program - An application of acquisition streamlining and Federal Aviation Administration Certification [AIAA PAPER 88-2123]

HIGUCHI, HIROSHI

Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714 HILEY, P. E.

Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary NASA-CR-177343-VOL-4 p 500 N88-22868

HINENO, YUTAKA Development overview of the T-2 CCV

p 528 A88-40527 HIRATA, HIDETOSHI

Structure and equipments of the T-2 CCV aircraft

p 514 A88-40530 HITZEL, STEPHAN M.

Wing vortex-flows up into vortex breakdown - A numerical simulation [AIAA PAPER 88-2518] p 487 A88-40709

HÒ, CHIH-MING Pressure measurements of impinging jet with asymmetric

[NASA-CR-182759] n 497 N88-22011

HO, P. Y. Scale model acoustic testing of counterrotating fans [AIAA PAPER 88-2057] p 523 A88-37947

HODGES, R. M., JR. Experimental and analytical aerodynamics of an

dvanced rotor in hover [AIAA PAPER 88-2530] p 488 A88-40717

HOEY, ROBERT G.

nozzle

Simulation in support of flight test - In retrospect [AIAA PAPER 88-2130] p 512 A88-38730

HOFF, A. M. METEOPOD, an airborne system for measurements of mean wind, turbulence, and other meteorological

[AIAA PAPER 88-2103] HOFF, JAMES E.

Maintainability - A design parameter

[AIAA PAPER 88-2184]

cloud physics parameters

p 474 A88-38753 HOFFMANN, HANS-EBERHARD Standardized ice accretion thickness as a function of

[ESA-TT-1080]

HÖFFMANN, S. K. The high technology test bed program - An overview [SAE PAPER 872312] p 507 A88-37183 p 507 A88-37183

HOLBEIN, REINHOLD Modern surface protections for aircraft

p 541 A88-39417

p 519 A88-38715

p 553 N88-23346

p 517 N88-22890

p 501 A88-37227

HOLLAND, RAINER Digital processing of flight data of a helicopter without using anti-aliasing filters

[ESA-TT-1094] HOLST, TERRY L.

Computational fluid dynamics drag prediction: Results from the Viscous Transonic Airfoil Workshop [NASA-TM-100095] p 496 N88-22009

HONAKER, JIM S.

Powered-lift transport aircraft certification criteria status

[SAE PAPER 872376] HOOPER, W. EUAN

Technology for advanced helicopters [SAE PAPER 872370]

p 509 A88-37224

### HORSTMANN, KARL-HEINZ

HORSTMANN, KARL-HEINZ

A multilifting line method and its application in design and analysis of nonplanar wing configurations

p 499 N88-22860 IDFVLR-FB-87-51 |

HOU, MING

Numerical calculations of a class of optimal flight p 553 A88-38178 trajectories

HOUTMAN, Z. M.

Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence p 499 N88-22861

HOWE, REX

A GPS hover position sensing system

p 503 A88-37390

HOWELL, JAN M.

Reliability and maintainability evaluation during flight test

[AIAA PAPER 88-2185]

p 474 A88-38754

HSIAO, FEI-BIN

Numerical prediction of aerodynamic performance for a low Reynolds number airfoil p 491 A88-40744 1 AIAA PAPER 88-25751

HSU, C.-H.

Navier-Stokes computation of flow around a round-edged double-delta wing p 494 A88-40767 | AIAA PAPER 88-2560 |

HSU, CHENG-CHIANG Numerical prediction of aerodynamic performance for

a low Reynolds number airfoil

p 491 A88-40744 [AIAA PÁPER 88-2575]

HSU. JOHN Y.

concepts for Expanded envelope control-element failure detection and identification p 507 N88-22886 INASA-CR-1816641

HUA. Q. D.

A digital P-code GPS reciever and its applications to p 503 A88-37393 embedded systems

HUANG, MINGKE

Application of efficient iteration scheme AF2 to computations of transonic full-potential flows over p 481 A88-38177 wing-body combinations

HUBAND, GARY W.

The numerical simulation of the Navier-Stokes equations for an F-16 configuration p 487 A88-40702

[AIAA PAPER 88-2507] HUBER, HELMUT B.

Current rotorcraft technology advancement at MBB p 476 A88-40562

HUCHER, MICHEL

Aerospace equipment - Evolution and future problems p 474 A88-40522

HUEBNER, LAWRENCE D.

Computational validation of a parabolized Navier-Stokes solver on a sharp-nose cone at hypersonic speeds p 490 A88-40739 [AIAA PAPER 88-2566]

HUI. K.

The application of linear maximum likelihood estimation of aerodynamic derivatives for the Bell-205 and Bell-206 p 518 N88-22894 [AD-A191279]

HUI, PATRICK J.

The Canadian Marconi Company GPS receiver - Its p 503 A88-37394 development, test, and future

HUNEKE, A. C.

GPS phase III multi-channel user equipment

p 503 A88-37378

HUNT, L. ROANE

Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 p 547 N88-22325 [NASA-TP-2804]

HUYER, STEPHEN A. Unsteady flow interactions between the wake of an

oscillating airfoil and a stationary trailing airfoil p 492 A88-40750 1 AIAA PAPER 88-2581 ] A comparative study of differing vortex structures arising

in unsteady separated flows p 492 A88-40751 TAIAA PAPER 88-25821

HYMAN, CURTIS E., JR.

Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel

p 497 N88-22016 INASA-TM-1005291

HYNES, CHARLES S.

Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft p 508 A88-37187

ISAE PAPER 8723161 HYNES, MARSHALL S.

Results of a precision hover simulation on the one-to-one motion Large Amplitude Research Simulator

p 509 A88-37218 [SAE PAPER 872356]

IANOVICE I

Visualisation of the flow at the tip of a high speed axial flow turbine rotor

IAD-A1899281 IDE. MASASHIRO p 546 N88-22300

Flight testing results of T-2 CCV p 528 A88-40529

IMMENSCHUH, WILLIAM

Design, construction and flight testing the Spirit of St. Louis p 557 A88-38755

[AIAA PAPER 88-2187]

INAGAKI, TOSHIHARU

First flight simulator test of the head-up display for NAL QSTOL experimental aircraft (ASUKA)

p 521 N88-22896 DE88-751804]

INDERHEES, MICHAEL E.

AQM-127A full scale engineering development Flight Test Program p 511 A88-38722

[AIAA PAPER 88-2121]

Turbulent eddy viscosity modeling in transonic

shock/boundary layer interactions p 493 A88-40758 [AIAA PAPER 88-2592] Computational simulation of vortex generator effects on

transonic shock/boundary layer interaction IAIAA PAPER 88-25901

ISHIDA, YOJI

control of Design method flow for laminar two-dimensional airfoils in incompressible flow. Numerical study of LFC design concepts p 498 N88-22859 [DE88-751809]

ISBAELI, M.

Numerical study of the skin friction on a spheroid at p 482 A88-38376 incidence

IWASAKI, ISAO

Trends and problems of head-up display

p 519 A88-40534

J

JACOBSON, S.

IR group activities at the Israel Aircraft Industries p 474 A88-40386

JANARDAN, B. A.
Scale model acoustic testing of counterrotating fans p 523 A88-37947 AIAA PAPER 88-2057] JANEX, A.

Reflections on the integration of avionics equipment p 519 A88-40517

JANKOWSKI, K.

The controlled system as a system with nonholonomic constraints - The case of a helicopter p 528 A88-39622

JANSEN, BERNARD

Supersonic jet plume interaction with a flat plate p 479 A88-37222 ISAE PAPER 8723611

JEFFREYS, N. E.

The use of the NRC/NAE water facilities in Canadian aeronautical research and development p 539 N88-23132

JENISTA, JOHN E.

Configuration E-7 supersonic STOVL fighter/attack

technology program ISAF PAPER 8723791 p 509 A88-37229 JENNINGS, R. D.

Investigations of test methodology for the stress loading facility [PB88-166095] n 538 N88-22049

JENSEN, OWEN E.

GPS overview -The operator's perspective p 502 A88-37377

JEON. C. S.

Correlation of entrainment and lift enhancement for a two-dimensional propulsive wing [SAE PAPER 872325] p 477 A88-37194

JERACKI, ROBERT J.

Porous wind tunnel corrections for counterrotation ropeller testing NASA-TM-1008731 p 498 N88-22019

JOGUET, J.-C.

Reflections on the integration of avionics equipment p 519 A88-40517

JOHNS, RAYMOND E.

I AIAA PAPER 88-21231

Air Force One replacement program - An application of acquisition streamlining and Federal Aviation Administration Certification p 474 A88-38723

JOHNSON, C. B.

Heating requirements and nonadiabatic surface effects for a model in the NTF cryogenic wind tunnel p 534 A88-37944 [AIAA PAPER 88-2044]

JOHNSON, WILLIAM G., JR.

A forecast of new test capabilities using Magnetic Suspension and Balance Systems

1 A1AA PAPER 88-20131

JOHST EBERHARD

New structural technologies for the Dornier 328 p 473 A88-37297

JONES, J. D. Active control of sound fields in elastic cylinders by

p 556 A88-39725 vibrational inputs JONES, W. P. The calculation of the flow through a two-dimensional p 485 A88-39030 faired diffuser

JUDD, MICHAEL

Flexiwall 3 SO: A second order predictive strategy for rapid wall adjustment in two-dimensional compressible

[NASA-CR-181662]

p 498 N88-22018

JUSTICE, J. H.

GPS phase III multi-channel user equipment p 503 A88-37378

KAGEYAMA, ISAO

Some topics of ASKA's flight test results and its future

[SAE PAPER 872317] KAIDEN, TAKESHI

Flow analysis around aircraft by viscous flow p 482 A88-38343 computation

KAISER, G. M.

GPS phase III multi-channel user equipment

p 503 A88-37378

KAISERSATT, THOMAS J. Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft

p 508 A88-37187 SAF PAPER 8723161

KAMEYAMA, TADASHI

FBW system and control law of the T-2 CCV

p 528 A88-40528

p 508 A88-37188

KANDA, HIROSHI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction p 539 N88-22911 INASA-TT-202091

KANIA, W.

Development of an airfoil of high lift/drag ratio and low moment coefficient for subsonic flow

p 495 A88-40972

KANKO, MARK A.

Geometric modeling of flight information for graphical cockpit display p 537 N88-22043 140-41904841

KANNO, HIDEKI

Development overview of the T-2 CCV p 528 A88-40527

KARCHMER, ALLEN M. Turbofan engine core noise source diagnostics

p 524 A88-39707

KARDYMOWICZ, ANDRZEJ Analysis of performance measurement results of

propeller aircraft. I - Flight performance p 514 A88-39481 Analysis of performance measurement results of aircraft. p 514 A88-40575

II - Flight performance

KASCAK, ALBERT F. Piezoelectric pushers for active vibration control of p 551 N88-23229 rotating machinery

KATAYÁNAGI, RYÓJI FBW system and control law of the T-2 CCV

p 528 A88-40528

KATO, AKIO Development overview of the T-2 CCV

p 528 A88-40527 KAUFMAN, ALBERT

Structural analyses of engine wall cooling concepts and p 542 N88-22405 materials

KAUPS, KALLE

Separation and reattachment near theleading edge of p 486 A88-39967 a thin wing

KAWAMURA, T. Calculation of external-internal flow fields for p 479 A88-37353 mixed-compression inlets

KAZA, KRISHNA RAO V. Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244

KEDZIE, CHRISTOPHER R.

Unsteady aerodynamic forces at low airfoil pitching rates

p 492 A88-40748 [AIAA PAPER 88-2579]

KEEN, J. M.		KOMOUCHI, YUTAKA		LAMBERT, MARK	
Applications of an Euler aero	odynamic method to	Development of fiber optic data bus for air	rcraft	NOTAR - The tail that wags the	doa
free-vortex flow simulation			A88-38344	and the same transfer and	p 510 A88-38696
[AIAA PAPER 88-2517]	p 487 A88-40708	KOTOVSKII, V. N.		LAMMERS, GERD	F 0.0 7.00 00000
KEENER, EARL R.		Computer simulation of turbulent jets and	wakes	Measurements of the time dep	pendent velocity field
Boundary-layer and wake measu	urements on a swept,		A88-37661	surrounding a model propeller in t	uniform water flow
circulation-control wing		KOZLOV, V. E.			p 550 N88-23155
[NASA-TM-89426]	p 497 N88-22013	Axisymmetric turbulent compressible jet	in subsonic	LANDRUM, D. B.	•
KEGELMAN, J. T.			A88-37665	Heating requirements and nona	diabatic surface effects
Unsteady features of jets in lift a	and cruise modes for	KRAVCHUK, L. V.		for a model in the NTF cryogenic	wind tunnel
VTOL aircraft		Model study of thermal stresses in gas-tu	rhine hlades	[AIAA PAPER 88-2044]	p 534 A88-37944
[SAE PAPER 872359]	p 478 A88-37220		N88-22989	LANE, JAMES W.	
KEHOE, MICHAEL W.		KRAVTSOVA, M. A.	1100 EE303	The RSRA/X-Wing experiment	- A status report
Aircraft flight flutter testing at the	NASA Ames-Dryden	Separation of a supersonic boundary layer	ahead of the	SAE PAPER 872371]	p 479 A88-37225
Flight Research Facility [AIAA PAPER 88-2075]			A88-37697	LANGE, M.	
	p 510 A88-38702	KREJSA, EUGENE A.	7100 07 007	A millimeter-wave low-range	radar altimeter for
KELLOGG, GARY V.		Combustion noise from gas turbine aircra	aft engines	helicopter applications - Experime	
Effects of update and refresh rate	es on flight simulation		A88-39708	, ,,	p 519 A88-39496
visual displays	E.E	KREPLIN, HP.	7100-03700	LANGHORNE, P. J.	P 0.0 7,00 00400
[NASA-TM-100415]	p 516 N88-22033	An experimental investigation of flowfi	ield about a	Vehicles and aircraft on floating	ice
KELLY, ARTHUR W.		multielement airfoil	cia about a	remende and another on noating	p 536 A88-40066
Power supply for an easily reconfig	gurable connectorless		A88-37937	LARKIN, ERIC W.	p 330 A00-40000
passenger-aircraft entertainment sys		KRISHNAMURTI, G.	7100 07007	An integrated approach to h	almat diantau auatau
KELLY JAMES W	p 513 A88-38800	Features and capabilities of the DOD sta	andard GPS	design	
KELLY, JAMES W.		receivers for aircraft and seaborne application			p 520 A88-41368
Stability flight test verification by r			A88-37379	LASHERAS, J. C.	
[AIAA PAPER 88-2129]	p 512 A88-38729	KROUTIL, J. C.	7.00-07070	Experimental and numerical an	alysis of the formation
KEMP, W. M.		Experimental investigation of Hover flowfie	alds in water	and evolution of streamwise vorti	
A role for fibre optics in antenna r		at the McDonnell Douglas Research Laborato	Ories	behind a flat plate	p 484 A88-39017
VEMP WILLIAM D. ID	p 544 A88-38116		N88-23135	LAURIEN, E.	
KEMP, WILLIAM B., JR.		KRYNYTZKY, A. J.	1100-20105	Interactive geometry definition a	and grid generation for
A panel method procedure for inte	rrrerence assessment	Mach number corrections for a two-foot p	propeller rig	applied aerodynamics	
in slotted-wall wind tunnels	- 507 400 :	in solid and slotted test sections	sponor ng	[AIAA PAPER 88-2515]	p 554 A88-40707
[AIAA PAPER 88-2537]	p 537 A88-40721		A88-37946	LAWING, PIERCE L.	
KEMPSTER, JOHN E.		KU, ZUO	700-07340	A forecast of new test capabil	ities using Magnetic
Rising to the challenge - Research		Linear dynamics of supersonic inlet		Suspension and Balance Systems	• •
KEBBEC W	p 475 A88-40555		A88-38186	[AIAA PAPER 88-2013]	p 532 A88-37921
KERRES, W.		KUBENDRAN, L. R.	7100-30100	LAWRENCE, SCOTT L.	
Short duration flow establishmen		Laser velocimeter measurements in a wing-fu	iselane type	Flow visualization and pressu	re distributions for an
Water-Ludwieg-Tunnel KHAIMOVICH, IZIDOR ARONOVICH	p 549 N88-23134	juncture	.oo.ago typo	all-body hypersonic aircraft	p 487 A88-40601
			N88-22012	LAWSON, C. L.	•
Radio-electronic equipment of airc		KUBO, AKIRA	1100-22012	Development of a block Lanczo	os algorithm for free
KHATTAB, A. A.	p 505 A88-37699	FBW system and control law of the T-2 CC	:V	vibration analysis of spinning struct	tures
			A88-40528	,	p 545 A88-40117
Separation and reattachment nea a thin wing		KUHN, RICHARD	7.00 40020	LAWSON, R. D.	p = 10 1100 10111
KHON'KIN, A. D.	p 486 A88-39967	Application of empirical and linear methods	s to VSTOL	Nondestructive evaluation of	arge scale composito
Turbulent friction on a delta wing	- 400 400 07057	powered-lift aerodynamics		components	argo scare composite
KIBENS, V.	p 480 A88-37657		A88-37236	[AD-A190998]	p 542 N88-22954
Unsteady features of jets in lift ar		KUHN, RICHARD E.		LECROY, ROY C.	p 0-12 1100-22334
VTOL aircraft	nd cruise modes for	Hover suckdown and fountain effects		Advanced tactical transport	noods and design
[SAE PAPER 872359]	- 470 400 07000		A88-37177	implications	neeus and design
KIMBERLIN, RALPH D.	p 478 A88-37220	KUSHMAN, K.	7100 07 777	[SAE PAPER 872337]	p 473 A88-37205
Performance flight tention of a sin		A plan for coupling wind tunnel testing	ı with CED	LEE, R.	p 473 A88-37205
Performance flight testing of a sin lift aircraft	igle engine powered	techniques	,		
(SAE PAPER 872314)	- 507 400 07405	[AIAA PAPER 88-1996] p 531	A88-37909	Scale model acoustic testing o [AIAA PAPER 88-2057]	
KIMURA, SHIGERU	p 507 A88-37185	KWAK, DOCHAN			p 523 A88-37947
Current trend of digital map proces	anina	An upwind differencing scheme for the time	ne-accurate	LEIGHTON, KENNETH P.	
Current trend or digital map proces		incompressible Navier-Stokes equations	io accurate	Acoustic characteristics of 1/20-s	icale model helicopter
KING, DANIEL C.	p 506 A88-40533		A88-40752	rotors	
Nondestructive evaluation of lar		, , ,	=	[NASA-CR-177355]	p 557 N88-23548
components	ge scale composite			LEISHMAN, J. GORDON	
[AD-A190998]				The Rotorcraft Center of Excelle	
	5 E40 NOO 00054				ince at the University
KISFI FV A E	p 542 N88-22954	<b>-</b>		of Maryland	ence at the University p 475 A88-40556
KISELEV. A. F.	•	LABARGE, W. L.	Í	of Maryland LEMAY, S. P.	p 475 A88-40556
KISELEV, A. F. Turbulent friction on a delta wing	•	KRASH parametric sensitivity study: Transpo	vrt category	of Maryland  LEMAY, S. P.  Leading edge vortex dynamics	p 475 A88-40556
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O.	p 480 A88-37657	KRASH parametric sensitivity study: Transpo airplanes	ort category	of Maryland  LEMAY, S. P.  Leading edge vortex dynamics wing	p 475 A88-40556
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research	p 480 A88-37657	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 l	ort category N88-22024	of Maryland  LEMAY, S. P.  Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]	p 475 A88-40556
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation	p 480 A88-37657 h Tunnel - A facility	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 I LACHARME, JEAN-PAUL	ort category N88-22024	of Maryland  LEMAY, S. P.  Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C.	p 475 A88-40556 on a pitching delta p 489 A88-40735
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997]	p 480 A88-37657	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 i LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen	ort category N88-22024	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing [AIAA PAPER 88-2559]  LESTER, HAROLD C.  Mechanisms of active control for n	p 475 A88-40556  on a pitching delta p 489 A88-40735  noise inside a vibrating
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 i LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer	N88-22024 nt boundary	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing [AIAA PAPER 88-2559]  LESTER, HAROLD C.  Mechanisms of active control for n cylinder	p 475 A88-40556 on a pitching delta p 489 A88-40735
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997]	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 ( LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 /	N88-22024 nt boundary	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C.  Mechanisms of active control for n cylinder  LEVINE, JACK	p 475 A88-40556  on a pitching delta p 489 A88-40735  noise inside a vibrating p 555 A88-39722
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 I LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 A LACKNEY, JOSEPH J.	ort category N88-22024 Int boundary A88-39623	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL	p 475 A88-40556  on a pitching delta p 489 A88-40735  noise inside a vibrating p 555 A88-39722
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T.	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p.515 if LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p.485 if LACKNEY, JOSEPH J. Specialty three-dimensional finite elements	N88-22024 Int boundary A88-39623	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AlAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for n cylinder  LEVINE, JACK  Overview of the US/UK ASTOVL [SAE PAPER 872365]	p 475 A88-40556  on a pitching delta p 489 A88-40735  noise inside a vibrating p 555 A88-39722
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 ( ACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 ( LACKNEY, JOSEPH J. Specialty three-dimensional finite elemen codes p 548 f	N88-22024 Int boundary A88-39623	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL	p 475 A88-40556  on a pitching delta     p 489 A88-40735  noise inside a vibrating     p 555 A88-39722  program
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inerti	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p.515 l  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p. 485 l  LACKNEY, JOSEPH J.  Specialty three-dimensional finite elemen- codes p.548 l  LADBURY, J. M.	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for neylinder  LEVINE, JACK Overview of the US/UK ASTOVL [SAE PAPER 872365]  LEWICKI, D. G.	p 475 A88-40556  on a pitching delta     p 489 A88-40735  noise inside a vibrating     p 555 A88-39722  program     p 473 A88-37238
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertice.	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402	KRASH parametric sensitivity study: Transpoairplanes [AD-A189962] p 515 I LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 J LACKNEY, JOSEPH J. Specialty three-dimensional finite element codes p 548 J LADBURY, J. M. EMR (Electromagnetic Radiation) test	ort category N88-22024 It boundary A88-39623 It analysis N88-22393 facilities	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AlAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for n cylinder  LEVINE, JACK  Overview of the US/UK ASTOVL [SAE PAPER 872365]	p 475 A88-40556  on a pitching delta     p 489 A88-40735  noise inside a vibrating     p 555 A88-39722  program     p 473 A88-37238
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 if LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 if LACKNEY, JOSEPH J. Specialty three-dimensional finite element codes LADBURY, J. M. EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 facilities of at RADC	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for noylinder  LEVINE, JACK  Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G.  Computerized life and reliability m	p 475 A88-40556  on a pitching delta     p 489 A88-40735  noise inside a vibrating     p 555 A88-39722  program     p 473 A88-37238
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inerti KNOTT, P. G. The ground environment created by vertical land aircraft	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust	KRASH parametric sensitivity study: Transpoairplanes [AD-A189962] p.515 [ LACHARME, JEAN-PAUL] Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p.485 [ LACKNEY, JOSEPH J.] Specialty three-dimensional finite element codes LADBURY, J. M. EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 If acilities If a RADC Interpretable of the RADC	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inerti KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309]	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p.515 [ACHARME, JEAN-PAUL] Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p. 485 [ACKNEY, JOSEPH J.] Specialty three-dimensional finite element codes LADBURY, J. M. EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 facilities If a RADC (Air Force	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for nocylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability matransmissions  [NASA-TM-100918]  LEWIS, LIANE C.	p 475 A88-40556 on a pitching delta     p 489 A88-40735 noise inside a vibrating     p 555 A88-39722 program     p 473 A88-37238 odelling for turboprop     p 551 N88-23220
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181	KRASH parametric sensitivity study: Transpo airplanes  [AD-A189962] p 515 if  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 if  LACKNEY, JOSEPH J.  Specialty three-dimensional finite element codes p 548 if  LADBURY, J. M.  EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p 538 in	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 If acilities If a RADC Interpretable of the RADC	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AlAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for neylinder  LEVINE, JACK  Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G.  Computerized life and reliability metansmissions  [NASA-TM-100918]	p 475 A88-40556 on a pitching delta     p 489 A88-40735 noise inside a vibrating     p 555 A88-39722 program     p 473 A88-37238 odelling for turboprop     p 551 N88-23220
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 87230] KOBAYASHI, OSAMU Some topics of ASKA's flight test re	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181	KRASH parametric sensitivity study: Transpo airplanes [AD-A189962] p 515 (LACHARME, JEAN-PAUL) Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 (LACKNEY, JOSEPH J.) Specialty three-dimensional finite element codes LADBURY, J. M. EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p 538 N	ort category N88-22024 Int boundary A88-39623 Int analysis N88-22393 If facilities If at RADC (Air Force	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of v.	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 vortex flows on delta
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inerti KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 esults and its future	KRASH parametric sensitivity study: Transpoairplanes [AD-A189962] p.515 [ACHARME, JEAN-PAUL] Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p.485 [ACKNEY, JOSEPH J.] Specialty three-dimensional finite element codes LADBURY, J. M. EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p.538 [ALGANELLI, A.] A plan for coupling wind tunnel testing	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 Int analysis In	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AlAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of wings in a water tunnel	p 475 A88-40556 on a pitching delta     p 489 A88-40735 noise inside a vibrating     p 555 A88-39722 program     p 473 A88-37238 odelling for turboprop     p 551 N88-23220
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inerti KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan [SAE PAPER 872317]	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 esults and its future p 508 A88-37188	KRASH parametric sensitivity study: Transponic airplanes  [AD-A189962] p 515 id  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulent layer using a laser Doppler anemometer p 485 in the sense of the s	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 Ifacilities If a HADC (Air Force N88-22048 With CFD	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for n cylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872965]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of v wings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C.	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 vortex flows on delta p 493 A88-40760
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KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inerti KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan [SAE PAPER 872317] Stability and control augmentation (SAE PAPER 872334) KOEPKE, G. H.	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 results and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203	KRASH parametric sensitivity study: Transponic airplanes  [AD-A189962] p 515 6  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulent layer using a laser Doppler anemometer p 485 6  LACKNEY, JOSEPH J.  Specialty three-dimensional finite element codes p 548 7  LADBURY, J. M.  EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p 538 N  LAGANELLI, A.  A plan for coupling wind tunnel testing techniques  [AIAA PAPER 88-1996] p 531 A  LAGRAFF, JOHN E.  An isentropic compression heated Ludw	ort category  N88-22024  Int boundary  A88-39623  Int analysis  N88-22393  facilities Int AADC (Air Force  N88-22048  With CFD  A88-37909  Wieg tube	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for noylinder  LEVINE, JACK  Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G.  Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C.  Nonintrusive measurements of wings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C.  Adaptive wall research with two- a models in low speed and transonic laids appear of the second of the se	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan [SAE PAPER 872317] Stability and control augmentation [SAE PAPER 872334] KOEPKE, G. H. EMR (Electromagnetic Radiatio	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 esults and its future p 508 A88-37188 h system of 'ASKA' p 527 A88-37203 on) test facilities	KRASH parametric sensitivity study: Transponing airplanes  [AD-A189962] p 515 [  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulent layer using a laser Doppler anemometer p 485 [  LACKNEY, JOSEPH J.  Specialty three-dimensional finite element codes p 548 [  LADBURY, J. M.  EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p 538 [  LAGANELLI, A.  A plan for coupling wind tunnel testing techniques  [AIAA PAPER 88-1996] p 531 A LAGRAFF, JOHN E.  An isentropic compression heated Ludw transient wind tunnel	ort category N88-22024 Int boundary A88-39623 Int analysis N88-22393 If acilities If at RADC (Air Force N88-22048 With CFD L A88-37909 Wieg tube L	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 87-2365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of wings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C.  Adaptive wall research with two-a models in low speed and transonic (AIAA PAPER 88-2037]  LEWIS, MARK CHARLES	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 vortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan [SAE PAPER 872317] Stability and control augmentation [SAE PAPER 872334] KOEPKE, G. H. EMR (Electromagnetic Radiatio evaluation of reverberating chamber	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 results and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203 con) test facilities located at RADC	KRASH parametric sensitivity study: Transpoairplanes [AD-A189962] p 515 ( LACHARME, JEAN-PAUL Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 ( LACKNEY, JOSEPH J. Specialty three-dimensional finite element codes LADBURY, J. M. EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB8-178827] p 538 N LAGANELLI, A. A plan for coupling wind tunnel testing techniques [AIAA PAPER 88-1996] p 531 A LAGRAFF, JOHN E. An isentropic compression heated Ludw transient wind tunnel [AIAA PAPER 88-2019] p 533 A	ort category  N88-22024  Int boundary  A88-39623  Int analysis  N88-22393  facilities Int AADC (Air Force  N88-22048  With CFD  A88-37909  Wieg tube	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AlAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of wings in a water tunnel  [AlAA PAPER 88-2595]  LEWIS, M. C. Adaptive wall research with two-amodels in low speed and transonic I  [AlAA PAPER 88-2037]  LEWIS, MARK CHARLES Aerofoil testing in a self-streamlinin	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 vortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan [SAE PAPER 872317] Stability and control augmentation [SAE PAPER 872334] KOEPKE, G. H. EMR (Electromagnetic Radiatio	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 results and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203 con) test facilities located at RADC	KRASH parametric sensitivity study: Transponic airplanes  [AD-A189962] p 515 id  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulent of the state o	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 Int analysis Int analysis Int analysis N88-22393 Int analysis Int a	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for noylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of wings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C. Adaptive wall research with two-amodels in low speed and transonic lalaA PAPER 88-2037]  LEWIS, MARK CHARLES  Aerofoil testing in a self-streamlinin tunnel	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 vortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 ag flexible walled wind
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KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O.  The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test replan [SAE PAPER 872317] Stability and control augmentation [SAE PAPER 872334] KOEPKE, G. H. EMR (Electromagnetic Radiatio evaluation of reverberating chamber (Rome Air Development Center), Griff Base), Rome, New York	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 results and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203 con) test facilities located at RADC	KRASH parametric sensitivity study: Transponic airplanes  [AD-A189962] p 515 [ACHARME, JEAN-PAUL]  Experimental study of a supersonic turbulent layer using a laser Doppler anemometer p 485 [ACKNEY, JOSEPH J.]  Specialty three-dimensional finite element codes  LADBURY, J. M.  EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p 538 [ABAPAELLI, A.  A plan for coupling wind tunnel testing techniques [AIAA PAPER 88-1996] p 531 [ABARAFF, JOHN E.  An isentropic compression heated Ludw transient wind tunnel [AIAA PAPER 88-2019] p 533 [ABAIA] [AIA, M. C.  The structure of sonic underexpanded turbule in still air	ort category N88-22024 Int boundary A88-39623 Int analysis N88-22393 If acilities If at RADC (Air Force N88-22048 With CFD A88-37909 Wieg tube LA88-37926 ent air jets L	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of wings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C. Adaptive wall research with two-a models in low speed and transonic 1  [AIAA PAPER 88-2037]  LEWIS, MARK CHARLES Aerofoil testing in a self-streamlinin tunnel  [NASA-CR-4128]  [EWIS, R. I.	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 og flexible walled wind p 499 N88-22865
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O.  The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test replan [SAE PAPER 872317] Stability and control augmentation [SAE PAPER 872334] KOEPKE, G. H. EMR (Electromagnetic Radiatio evaluation of reverberating chamber (Rome Air Development Center), Griff Base), Rome, New York	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 esults and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203 on) test facilities located at RADC fifts AFB (Air Force	KRASH parametric sensitivity study: Transponic airplanes  [AD-A189962] p 515 6  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulent of the study of a supersonic turbulent of the study of a supersonic turbulent of the study of a supersonic turbulent of turbulent of a supersonic turbulent of turbulent of turbulent of p 485 6  LACKNEY, JOSEPH J.  Specialty three-dimensional finite element codes p 548 7  LAGBURY, J. M.  EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p 538 N  [PB88-178827] p 538 N  LAGANELLI, A.  A plan for coupling wind tunnel testing techniques [AIAA PAPER 88-1996] p 531 A  LAGRAFF, JOHN E.  An isentropic compression heated Ludw transient wind tunnel [AIAA PAPER 88-2019] p 533 A  LAI, M. C.  The structure of sonic underexpanded turbule in still air [AD-A190856] p 500 N	ort category N88-22024 Int boundary A88-39623 Int analysis N88-22393 If acilities If at RADC (Air Force N88-22048 With CFD A88-37909 Wieg tube A88-37926 ent air jets	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AlAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of wings in a water tunnel  [AlAA PAPER 88-2595]  LEWIS, M. C. Adaptive wall research with two-amodels in low speed and transonic talka Paper 88-2037]  LEWIS, MARK CHARLES Aerofoil testing in a self-streamlinin tunnel  [NASA-CR-4128]  EWIS, R. I. Recent developments and engine	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 rg flexible walled wind p 499 N88-22865 rering applications of
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan [SAE PAPER 872317] Stability and control augmentation [SAE PAPER 872334] KOEPKE, G. H. EMR (Electromagnetic Radiatio evaluation of reverberating chamber (Rome Air Development Center), Griff Base), Rome, New York [PB88-178827] KOHLHEPP, FRED W.	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 results and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203 con) test facilities located at RADC ffiss AFB (Air Force	KRASH parametric sensitivity study: Transponing airplanes  [AD-A189962] p 515 d  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulent layer using a laser Doppler anemometer p 485 d  LACKNEY, JOSEPH J.  Specialty three-dimensional finite element codes p 548 d  LADBURY, J. M.  EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York [PB88-178827] p 538 d  LAGANELLI, A.  A plan for coupling wind tunnel testing techniques  [AIAA PAPER 88-1996] p 531 A  LAGRAFF, JOHN E.  An isentropic compression heated Ludw transient wind tunnel  [AIAA PAPER 88-2019] p 533 A  LAI, M. C.  The structure of sonic underexpanded turbule in still air  [AD-A190856] p 500 N  LAMARCHE, L.	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 Int analysis In	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of vivings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C. Adaptive wall research with two-amodels in low speed and transonic IAIAA PAPER 88-2037]  LEWIS, MARK CHARLES Aerofoil testing in a self-streamlinin tunnel  [NASA-CR-4128]  LEWIS, R. I.  Recent developments and engine the vortex cloud method	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 og flexible walled wind p 499 N88-22865
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test re plan [SAE PAPER 872317] Stability and control augmentation (SAE PAPER 872334) KOEPKE, G. H. EMR (Electromagnetic Radiatio evaluation of reverberating chamber (Rome Air Development Center), Grift Base), Rome, New York [PB88-178827]	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 results and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203 con) test facilities located at RADC ffiss AFB (Air Force	KRASH parametric sensitivity study: Transpoairplanes  [AD-A189962] p 515 id  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulen layer using a laser Doppler anemometer p 485 id  LACKNEY, JOSEPH J.  Specialty three-dimensional finite element codes  LADBURY, J. M.  EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located (Rome Air Development Center), Griffiss AFB Base), Rome, New York  [PB88-178827] p 538 in  LAGANELLI, A.  A plan for coupling wind tunnel testing techniques  [AIAA PAPER 88-1996] p 531 in  LAGRAFF, JOHN E.  An isentropic compression heated Ludw transient wind tunnel  [AIAA PAPER 88-2019] p 533 in  LAI, M. C.  The structure of sonic underexpanded turbule in still air  [AD-A190856] p 500 in  LAMARCHE, L.  The use of 2-D adaptive wall test section	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 Int analysis In	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 87-2365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of vivings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C. Adaptive wall research with two-a models in low speed and transonic of the control of	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 noise inside a vibrating p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 noise inside walled wind p 499 N88-22865 noise inside a vibrating applications of p 480 A88-37358
KISELEV, A. F. Turbulent friction on a delta wing KJELGAARD, SCOTT O. The Basic Aerodynamics Research dedicated to code validation [AIAA PAPER 88-1997] KLANN, ERNST CFRP landing flaps for the Airbus A KNIGHT, DONALD T. GPS integration with low-cost inertic KNOTT, P. G. The ground environment created by vertical land aircraft [SAE PAPER 872309] KOBAYASHI, OSAMU Some topics of ASKA's flight test replan [SAE PAPER 872317] Stability and control augmentation [SAE PAPER 872334] KOEPKE, G. H. EMR (Electromagnetic Radiatio evaluation of reverberating chamber (Rome Air Development Center), Griff Base), Rome, New York [PB88-178827] KOHLHEPP, FRED W. Acoustic characteristics of 1/20-sca	p 480 A88-37657 h Tunnel - A facility p 531 A88-37910 A320 p 474 A88-39416 ial navigation unit p 504 A88-37402 y high specific thrust p 477 A88-37181 results and its future p 508 A88-37188 n system of 'ASKA' p 527 A88-37203 con) test facilities located at RADC ffiss AFB (Air Force	KRASH parametric sensitivity study: Transponic airplanes  [AD-A189962] p 515 id  LACHARME, JEAN-PAUL  Experimental study of a supersonic turbulent layer using a laser Doppler anemometer p 485 in the sum of the	nt category N88-22024 Int boundary A88-39623 Int analysis N88-22393 Int analysis In	of Maryland  LEMAY, S. P. Leading edge vortex dynamics wing  [AIAA PAPER 88-2559]  LESTER, HAROLD C. Mechanisms of active control for ncylinder  LEVINE, JACK Overview of the US/UK ASTOVL  [SAE PAPER 872365]  LEWICKI, D. G. Computerized life and reliability m transmissions  [NASA-TM-100918]  LEWIS, LIANE C. Nonintrusive measurements of vivings in a water tunnel  [AIAA PAPER 88-2595]  LEWIS, M. C. Adaptive wall research with two-amodels in low speed and transonic IAIAA PAPER 88-2037]  LEWIS, MARK CHARLES Aerofoil testing in a self-streamlinin tunnel  [NASA-CR-4128]  LEWIS, R. I.  Recent developments and engine the vortex cloud method	p 475 A88-40556 on a pitching delta p 489 A88-40735 noise inside a vibrating p 555 A88-39722 program p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 noise inside a vibrating p 473 A88-37238 odelling for turboprop p 551 N88-23220 rortex flows on delta p 493 A88-40760 and three-dimensional tunnels p 533 A88-37939 noise inside walled wind p 499 N88-22865 noise inside a vibrating applications of p 480 A88-37358

A study of digital fly-by-wire control system design for elastic aircraft p 527 A88-38191

### **LIAN, QIXIANG**

LIAN, QIXIANG Experimental investigation on rigid hollow hemispherical parachute model in accelerating and steady flow p 482 A88-38185 LIDDELL, P. W. A supersonic design with V/STOL capability p 509 A88-37231 |SAE PAPER 872382| LIN, BINGQIU Theoretical model and numerical solution compressible viscous vortex cores p 498 N88-22243 LIN. FUJIA Some aspects of the reliability analysis of aircraft LINDNER, M. IR group activities at the Israel Aircraft Industries p 474 A88-40386 LINDSAY, ROBERT A. Flight test imagery - Getting more for less [AIAA PAPER 88-2102] p 505 p 505 A88-38714 LINGAIAN, K. Addendum-dedendum type circular-arc gears for aero-engine accessory drive gearbox - A critical analysis p 545 A88-40280 of strength-to-weight ratio LINSE, DENNIS Analysis of a range estimator which uses MLS angle measurements p 507 N88-22884 [NASA-CR-182896] LISSAK, Z. IR group activities at the Israel Aircraft Industries p 474 A88-40386 LIU, C. H. Navier-Stokes computation of flow around a round-edged double-delta wing p 494 A88-40767 I AIAA PAPER 88-2560 I LIU, H.-T. Unsteady aerodynamics of a Wortmann FX-63-137 wing in a fluctuating wind field p 496 N88-22006 [AD-A190128] LIÙ, WEI Mixed direct-inverse problem of transonic cascade p 498 N88-22244 LO. CHING F. Direct assessment of two-dimensional wind-tunnel interference from measurements on two interfaces | AIAA PAPER 88-2539 | p 537 A88-40723 LOCKMAN, WILLIAM K. Flow visualization and pressure distributions for an p 487 A88-40601 all-body hypersonic aircraft LOEWY, ROBERT G. Research at Rensselaer Polytechnic Institute's Center of Excellence in rotorcraft technology p 475 A88-40557 LOMBARD, C. K. CSCM Navier-Stokes thermal/aerodynamic analysis of hypersonic nozzle flows with slot injection and wall p 493 A88-40756 [ AIAA PAPER 88-2587 ] LONG. D. F. Development of a control system for an injector powered transonic wind tunnel p 535 A88-37950 [AIAA PAPER 88-2063] LOSEV, VIKTOR SEMENOVICH Flight fatigue testing of helicopters p 510 A88-37703 LOTH, JOHN L. Thrust efficiency of powered lift systems p 522 A88-37196 [SAE PAPER 872327] Estimation of thrust augmentor performance in V/STOL applications p 522 A88-37192 SAF PAPER 8723231 LUTTGES, M. Visualization and anemometry analyses of forced unsteady flows about an X-29 model [AIAA PAPER 88-2570] LUTTGES, MARVIN W. Unsteady flow interactions between the wake of an oscillating airfoil and a stationary trailing airfoil p 492 A88-40750 [AIAA PAPER 88-2581] A comparative study of differing vortex structures arising in unsteady separated flows p 492 A88-40751 [AIAA PAPER 88-2582] LYNN, ROBERT R. Aircraft without airports - Changing the way men fly p 476 A88-40559

MABEY, D. G. On the prospects for increasing dynamic lift p 481 A88-38167 MACCORMACK, R. W.

On the validation of a code and a turbulence model appropriate to circulation control airfoils [NASA-TM-100090]

p 499 N88-22864

MACHA, J. M.

Heating requirements and nonadiabatic surface effects for a model in the NTF cryogenic wind tunnel p 534 A88-37944 AIAA PAPER 88-2044] MACKALL, D. A.

The NASA Integrated Test Facility and its impact on flight research

[AIAA PAPER 88-2095] p 535 A88-38711

MAGARI, PATRICK J.

An isentropic compression heated Ludwieg tube transient wind tunnel

p 533 A88-37926 [AIAA PAPER 88-2019] MAGILL, L. G.

Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil

p 543 N88-23011

[AD-A190120] MAHAJAN, APARAJIT J.

Reduced order models for nonlinear aerodynamics p 501 N88-23248

MAHAPATRA, P. R.

ILS glidescope evaluation of imperfect terrain

p 506 A88-39135

MAHONEY, KATHLEEN Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872348] p 523 A88-37237 p 523 A88-37237

MAHOON, A. The role of non-destructive testing in the airworthiness

certification of civil aircraft composite structures p 545 A88-40175 MALCOLM, GERALD N.

Nonintrusive measurements of vortex flows on delta wings in a water tunnel

p 493 A88-40760 [AIÃA PAPER 88-2595] Water facilities in retrospect and prospect: An uminating tool for vehicle design p 539 N88-23126 illuminating tool for vehicle design Flow visualization study of vortex manipulation on fighter configurations at high angles of attack

p 549 N88-23130

MALONE, J. B. A comparison of numerical algorithms for unsteady p 480 A88-37360 transonic flow

MANDERS, P. J. H. M. Reliability analysis within a Computer Aided Engineering

(CAF) infrastructure p 547 N88-22369 NLR-MP-86059-U]

MANKBADI, R. R. Computational study of the unsteady flow due to wakes p 483 A88-38984 passing through a channel

The calculation of the flow through a two-dimensional faired diffuser p 485 A88-39030

MANNING, JAMES C.

Supersonic jet plume interaction with a flat plate [SAE PAPER 872361] p 479 A88 p 479 A88-37222

MANSELL, MICHAEL

Applying vectored thrust V/STOL experience in supersonic designs [SAE PAPER 872381] n 509 A88-37230

MANSUR, M. HOSSEIN

An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 52

p 529 N88-22905 MANTEL, B.

On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite p 495 A88-41269 element methods

MARBLE, FRANK E. Investigation of combustion in large vortices

p 541 N88-22121 LAD-A1904061 MARCONI, FRANK On the prediction of highly vortical flows using an Euler

equation model, part 2 p 547 N88-22305 [AD-A190245]

MARESCA, C. Experimental and numerical study of the propeller/fixed

wing interaction p 491 A88-40742 [AIAA PAPER 88-2571]

MARGASON, RICHARD Propulsion-induced effects caused by out-of-ground

effects p 477 A88-37179 [SAE PAPER 872307] Application of empirical and linear methods to VSTOL

nowered-lift aerodynamics [SAE PAPER 872341] p 479 A88-37236

MARK, HANS

Aircraft without airports - Changing the way men fly p 476 A88-40559

MARK, J. G. Integration of GPS receivers into existing inertial p 504 A88-37399 navigation systems

MARTELLUCCI, A. A plan for coupling wind tunnel testing with CFD techniques [AIAA PAPER 88-1996] p 531 A88-37909 MARTIN, R. M.

retreating-side and directivity Advancing-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710

MARTIN, ROBERT J.

A study of failure characteristics in thermoplastic composite material

p 542 N88-22940 [AD-A190613]

MARTINDALE, W. R. Study on needs for a magnetic suspension system operating with a transonic wind tunnel p 533 A88-37922

[AIAA PAPER 88-2014] MARTINI, K. F.

Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137] p 556 N88-23545

MARTIROSYAN, A. M.

Dependence of structure of stabilized ZrO2 coatings on p 543 N88-22990 condensation rate

MARX, ROBERY I.

Air Force One replacement program - An application of acquisition streamlining and Federal Aviation Administration Certification

p 474 A88-38723 [AIAA PAPER 88-2123] MARYNIAK, J.

The controlled system as a system with nonholonomic constraints - The case of a helicopter p 528 A88-39622

MASSARDO, ARISTIDE

The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112

MATHES, JAMES R., JR.

Model selection for the multiple model adaptive algorithm for in-flight simulation p 515 N88-22022

MATHEWS, ROGER H.

Near term enhancements of the AV-8B Harrier II p 508 A88-37190 [SAE PAPER 872321] MAZZA, L. T.

Special report on Bell ACAP full-scale aircraft crash

ISAE PAPER 8723621 n 509 A88-37223

MCARDLE, JACK G.

Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion p 523 A88-37217 [SAE PAPER 872355]

MCCARTY, ROBERT E. Analytical evaluation of birdstrike against a F-16A laminated canopy

p 514 A88-40868 [AIAA PAPER 88-2268]

MCCURDY, DAVID A. Advanced turboprop aircraft flyover noise: Annoyance

to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results p 557 N88-23547 [NASA-TM-100612]

MCGINLEY, CATHERINE B.

Riblet drag reduction at flight conditions [AIAA PAPER 88-2554] p 49 p 494 A88-40764 MČGURIK, J. J.

The turbulence characteristics of a single impinging jet p 545 A88-39012 through a crossflow

MCLEAN, BILL Developing a wide field of view HMD for simulators p 520 A88-41367

MCMILLIN, S. NAOMI

Experimental and theoretical study of the effects of wing geometry on a supersonic multibody configuration p 494 A88-40766 AIAA PAPER 88-2510]

MCMINN, JOHN D. A description of an automated database comparison

NASA-TM-1006091 p 554 N88-23463 MCNALLY, B. DAVID

Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model

[AIAA PAPER 88-2134] p 512 A88-38731

MCREE, GRIFFITH J.

Aerodynamic investigation by infrared imaging [AIAA PAPER 88-2523] p 545 A8

p 545 A88-40713

Optimum porosity for an inclined-hole transonic test section wall treated for edgetone noise reduction

p 531 A88-37914 [AIAA PAPER 88-2003] MEHMED, ORAL Propfan model wind tunnel aeroelastic research

p 501 N88-23246 MEHTA, R.

Experimental studies of vortex flows

p 551 N88-23171 [NASA-CR-182874]

MEHTA, RABINDRA D.

Properties of a half-delta wing vortex p 483 A88-38985

Contraction design for small low-speed wind tunnels p 537 N88-22045 INASA-CR-1827471

84	<b>C</b> 1	DI	JΑ	•	_

Experimental and numerical analysis of the formation and evolution of streamwise vortices in the plane wake behind a flat plate p 484 A88-39017

MELLANO, W.

Rapid prototyping of complex avionics system architectures IETN-88-922751

MELSON, N. DUANE

p 521 N88-22898

Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector

splitting [AIAA PAPER 88-2516] MELZER, JAMES E.

p 493 A88-40762

An integrated approach to helmet display system p 520 A88-41368 MEYER, ROBERT R. JR.

Techniques used in the F-14 variable-sweep transition flight experiment [AIAA PAPER 88-2110]

MEYERS, JAMES F.

p 513 A88-38762

Measurement of leading edge vortices from a delta wing using a three component laser velocimeter [AIAA PAPER 88-2024] p 544 A88-37929

MICKLE, EUGENE A.

T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403

system

A highly monitored AV-8B Harrier II digital flight control SAE PAPER 872332]

MIGNOSI, A.

p 527 A88-37201

Two-dimensional and three-dimensional adaptation at the T2 transonic wind tunnel of Onera/Cert

[AIAA PAPER 88-2038] MIHALOEW, JAMES R.

p 534 A88-37940

Flight propulsion control integration for V/STOL aircraft

[SAE PAPER 872330] MIKHEEV, ROSTISLAV ALEKSANDROVICH

p 522 A88-37199

Flight fatigue testing of helicopters

p 510 A88-37703

MILFORD, C. M.

Hot gas recirculation in V/STOL [SAE PAPER 872306]

p 477 A88-37178

MILLS, CHARLENE

Keys to a successful flight test [AIAA PAPER 88-2174]

p 519 A88-38766

Piezo-electric foils as a means of sensing unsteady surface forces on flow-around bodies

n 483 A88-38976

MITSUHASHI, KIYOMICHI

Optical technology application in aircraft

p 474 A88-40532 MIWA. HITOSHI

Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911

MIYAKAWA, JUNICHI

Flow analysis around aircraft by viscous flow computation p 482 A88-38343

MOOK, D. T.

Numerical simulation of wings in steady and unsteady ground effects [AIAA PAPER 88-2546] p 488 A88-40728

MOORE, ARCHIE L.

Development of an integrated set of research facilities

for the support of research flight test [AIAA PAPER 88-2096] p 535 A88-38712

Development of a mobile research flight test support [AIAA PAPER 88-2087]

p 536 A88-38761 Development of a mobile research flight test support capability

[NASA-TM-100428] p 506 N88-22883

MOORHEAD, PAUL E.

High-temperature combustor liner tests in structural component response test facility p 525 N88-22383

MORALEZ, ERNESTO, III

Integrated control and display research for transition and vertical flight on the NASA V/STOL Research Aircraft (VSRA)

[SAE PAPER 872329] p 526 A88-37198

MORGAN, H. L.

An experimental investigation of flowfield about a multielement airfoil

[AIAA PAPER 88-2035] p 481 A88-37937

MORRELL, F. R.

Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit

[AIAA PAPER 88-2172]

p 553 A88-38765

MORRIS, STEVEN L.

Nonintrusive measurements of vortex flows on delta

MOTYKA, P. R.

[AIAA PAPER 88-2595] p 493 A88-40760

Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit [AIAA PAPER 88-2172] p 553 A88-38765

MOUCH, T.

Visualization and anemometry analyses of forced

unsteady flows about an X-29 model [AIAA PAPER 88-2570] p 490 A88-40741

MOULTON, BRYAN J.

Effects of maneuver dynamics on drag polars of the X-29A forward-swept-wing aircraft with automatic wing camber control

[AIAA PAPER 88-2144]

p 527 A88-38737

p 514 A88-39277

MOXON, JULIAN

V-22 Osprey - Changing the way man flies

MUCHMORE, C. B., JR.

The effects of canard-wing flow-field interactions on longitudinal stability, effective dihedral and potential deep-stall trim

[AIAA PAPER 88-2514]

p 528 A88-40706

MUELLER, B.

Comparison of Euler and Navier-Stokes solutions for vortex flow over a delta wing p 485 A88-39278

MULCARE, D. B.

Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901

MUNGAL, M. G.

Turbulent reacting flows and supersonic combustion [AD-A189690] p 541 N88-22115

MURTHY, DURBHA V.

A computational procedure for automated flutter analysis p 530 N88-23250

MYERS, LAWRENCE P.

Performance improvements of an F-15 airplane with an integrated engine-flight control system [AIAA PAPER 88-2175]

p 527 A88-38747

NAARDING, STEVE H. J.

Experimental and numerical investigation of the vortex flow over a yawed delta wing

NAGATA, JOHN I.

[AIAA PAPER 88-2563] p 490 A88-40737

Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing

[AD-A190604] p 516 N88-22029 Airworthiness and flight characteristics test of a ski

assembly for the UH-60A Black Hawk helicopter p 518 N88-22895

NAIK, D. A.

Experimental investigation of non-planar sheared outboard wing planforms [AIAA PAPER 88-2549] p 489 A88-40731

NAKAO, MASATO

Flight testing results of T-2 CCV p 528 A88-40529 NAKAYAMA. A.

An experimental investigation of flowfield about a multielement airfoil [AJAA PAPER 88-2035] p 481 A88-37937

NAKAZAWA, S.

MHOST: An efficient finite element program for inelastic analysis of solids and structures p 525 N88-22394 NAOR, DANIEL

A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 p 520 A88-41369

NARAYANAN, G. V.

Modal forced response of propfans in yawed flow p 551 N88-23253

NATH G

Unsteady nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular cylinder p 495 A88-40970

NEAL, G.

Adaptive wall research with two- and three-dimensional models in low speed and transonic tunnels [AIAA PAPER 88-2037] p 533 A88-37939

NEIL, JEFFREY T.

Improving the reliability of silicon nitride - A case study p 540 A88-38316

NELSON, ANDREW

Results of dynamic testing of the USAF/ESMC GPS user equipment aboard the range tracking ships USNS Observation Island and USNS Redstone

p 503 A88-37385

NELSON, DAVID W.

Determination of the aerodynamic characteristics of the Mission Adaptive Wing

[AIAA PAPER 88-2556] p 489 A88-40733

NELSON, R. C.

Visualization and wake surveys of vortical flow over a p 482 A88-38377 Leading edge vortex dynamics on a pitching delta

(AIAA PAPER 88-2559) p 489 A88-40735

NELSON, RICHARD S. Life prediction modeling based on cyclic damage

accumulation p 548 N88-22426 NELSON, ROBERT C. Visualization techniques for studying high angle of attack

separated vortical flows [AIAA PAPER 88-2025] p 544 A88-37930 NÈSEL, MICHAEL C.

Real-time flight test data distribution and display [NASA-TM-100424] p 538 N88-22050

NEWMAN, PERRY A. Unsteady viscous-inviscid interaction procedures for

transonic airfoils using Cartesian grids
[AIAA PAPER 88-2591] p 493 A88-40757 NG, T. T.

Visualization and wake surveys of vortical flow over a delta wing p 482 A88-38377

NICHOLAS, O. P. The VAAC VSTOL flight control research project

[SAE PAPER 872331] p 526 A88-37200 NIELSON, JOHN T.

T-33 aircraft demonstration of GPS aided inertial navigation p 504 A88-37403

NIGIM H. H. Modelling the influence of small surface discontinuities

in turbulent boundary layers [AIAA PAPER 88-2594] p 546 A88-40759 NISSLEY, DAVID M.

Fatigue damage modeling for coated single crystal uperalloys p 542 N88-22427 superallovs

NITSCHE, W. Piezo-electric foils as a means of sensing unsteady surface forces on flow-around bodies

p 483 A88-38976

NIU. KEISHIRO

Analysis for high compressible supersonic flow in converging nozzle [1088.1.490] p 500 N88-22869

NIXON, DAVID Turbulence and fluid/acoustic interaction in impinging

iets [SAE PAPER 872345] p 478 A88-37211

NIXON, MARK W.

Improvements to tilt rotor performance through passive blade twist control

[NASA-TM-100583] p 548 N88-22434

NORTON, CARL An interactive method for modifying numerical model wind forecasts p 552 A88-38679

NOWLIN, BRENT C. Small engine components test facility turbine testing

[NASA-TM-100887] p 525 N88-22037 NUHAIT, A. O. Numerical simulation of wings in steady and unsteady

around effects [AIAA PAPER 88-2546] p 488 A88-40728

0

OBRIEN, T. KEVIN Towards a damage tolerance philosophy for composite

materials and structures [NASA-TM-100548] p 542 N88-22949 ODEN, J. TINSLEY

World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986, Proceedings p 544 A88-37351

OGINO, SABURO Status and trend in CCV

OGUNI, YASUO Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911

OHASHI, TOSHIJI

Structure and equipments of the T-2 CCV aircraft p 514 A88-40530

OHMIYA, HIDEAKI

Flight testing results of T-2 CCV p 528 A88-40529 OKADA, NORIAKI

Stability and control augmentation system of 'ASKA' [SAE PAPER 872334] p 527 A88-37203

p 528 A88-40526

Fourth-order accurate calculations of the 3-D

RADWAN, SAMIR F.

### OLCMEN, SEMIH

Flight test of the Japanese USB STOL experimental

PEAKE D.J.

Vortex breakdown and control experiments in the

aircraft ASKA layers on aerospace compressible boundary p 549 N88-23127 p 513 A88-38750 Ames-Dryden water tunnel | AIAA PAPER 88-2180 | configurations PEAKE, DAVID J. OLCMEN, SEMIH [AIAA PAPER 88-2522] p 487 A88-40712 Water facilities in retrospect and prospect: illuminating tool for vehicle design p 539 N88-20 Measurements of turbulent flow behind a wing-body p 539 N88-23126 RAINBIRD, W. J. p 484 A88-38987 iunction Optimum porosity for an inclined-hole transonic test PERIAUX. J. OLSON, LAWRENCE E. section wall treated for edgetone noise reduction On the use of subcycling for solving the compressible Aerodynamic flow quality and acoustic characteristics p 531 A88-37914 I AIAA PAPER 88-20031 Navier-Stokes equations by operator-splitting and finite of the 40- by 80-foot test section circuit of the National RAINEN, RICHARD A. p 495 A88-41269 element methods Full-Scale Aerodynamic Complex Elevated-temperature Al alloys for aircraft structure ISAE PAPER 8723281 p 530 A88-37197 PERNICE, C. p 541 A88-40486 Correlation of entrainment and lift enhancement for a OMEL'CHENKO, V. V. two-dimensional propulsive wing Life of gas turbine engine disks with cracks Applications of an Euler aerodynamic method to p 477 A88-37194 [SAE PAPER 872325] p 544 A88-37549 free-vortex flow simulation PETRY, JOSEF ORINICHEV, I. S. p 487 A88-40708 IAIAA PAPER 88-25171 Servo-actuator control for sampled-data feedback Thermal state of a turbofan rotor p 545 A88-40317 RAMACHANDRA, K. disturbance rejection OSHIMA, TAKAO Addendum-dedendum type circular-arc gears for p 528 A88-40526 1ESA-TT-10021 p 529 N88-22903 Status and trend in CCV aero-engine accessory drive gearbox - A critical analysis PFEIFFER, NEAL J. OSTOWARI, C. of strength-to-weight ratio p 545 A88-40280 Flowfield study at the propeller disks of a twin pusher, Experimental investigation of non-planar sheared RAMSEY, JOHN K. outboard wing planforms canard aircraft p 552 N88-23255 Supersonic axial-flow fan flutter p 489 A88-40731 p 514 A88-40704 [AIAA PAPER 88-2511] | AIAA PAPER 88-2549 | Wake rake studies behind a swept surface, canard RAPP, DAVID C. OWEN, F. K. Parametric study of supersonic STOVL flight Vortex breakdown and control experiments in the aircraft p 549 N88-23127 characteristics [AIAA PAPER 88-2552] p 489 A88-40732 Ames-Dryden water tunnel p 518 N88-22893 [NASA-CR-177330] OWEN, G. S. PFENNINGER, W.
Design of low Reynolds number airfoils. I Water flow visualisation of a ramrocket combustion RASPET, RICHARD p 549 N88-23138 p 494 A88-40765 Estimation of turbulence effects on sound propagation [AIAA PAPER 88-2572] chamber p 555 A88-39712 OWENS, WILLIAM R. from low flying aircraft PHAM, CANH T. Power supply for an easily reconfigurable connectorless A new method to confirm category III autoland passenger-aircraft entertainment system Microprocessor control of high-speed wind tunnel nerformance p 513 A88-38800 p 505 A88-38726 AIAA PAPER 88-2126] stagnation pressure p 535 A88-37949 OZCAN, OKTAY [AIAA PAPER 88-2062] PHILLIPS, PAMELA S. Measurements in a three-dimensional turbulent RAY, EDWARD J. A transonic wind tunnel wall interference prediction p 484 A88-39000 boundary-layer Highlights of experience with a flexible walled test code OZGAN, OKTAY section in the NASA Langley 0.3-meter transonic cryogenic p 537 A88-40722 [AIAA PAPER 88-2538] Measurements of turbulent flow behind a wing-body inction p 484 A88-38987 tunnel PICKETT, M. D. [AIAA PAPER 88-2036] p 533 A88-37938 iunction The NASA Integrated Test Facility and its impact on RÀY, R. J. flight research Development of a real-time aeroperformance analysis echnique for the X-29A advanced technology p 535 A88-38711 [AIAA PAPER 88-2095] technique PILAND, WILLIAM M. demonstrator PAGENDARM, H. G. National Aero-Space Plane [AIAA PAPER 88-2145] p 512 A88-38738 Interactive geometry definition and grid generation for p 540 A88-41288 IAAS PAPER 87-1271 RÉADER, KENNETH R. applied aerodynamics 1987 Technical Committee Highlights - The year in PILON, P. [AIAA PAPER 88-2515] p 554 A88-40707 Development of a variational method for chemical kinetic p 475 A88-40558 review PAIELLI, R. A. p 541 A88-38490 sensitivity analysis REAVIS, MARK A. Helicopter terminal approach using differential GPS with A comparative study of differing vortex structures arising PIRZADEH, SHAHYAR p 503 A88-37397 vertical-axis enhancement Three-dimensional unsteady transonic viscous-inviscid in unsteady separated flows PALAZZOLO, ALAN B. interaction using the Euler and boundary-layer equations p 492 A88-40751 [AIAA PAPER 88-2582] Piezoelectric pushers for active vibration control of p 491 A88-40747 [AIAA PAPER 88-2578] REDDY, T. S. R. p 551 N88-23229 rotating machinery p 552 N88-23256 Stall flutter analysis of propfans PITTMAN, JAMES L. PAMADI, BANDU N. Computational validation of a parabolized Navier-Stokes REDEKER, A. The effect of cross flow angle on the drag and lift An airborne realtime data processing and monitoring solver on a sharp-nose cone at hypersonic speeds coefficients of non-circular cylinder with strakes p 490 A88-40739 [AIAA PAPER 88-2566] system for research aircraft p 493 A88-40761 1AIAA PAPER 88-25991 p 506 A88-38743 [AIAA PAPER 88-2165] PLISCHKE, FRANZ PANARAS, A. G. REDING, J. P. The effect of aircraft angular vibrations on the quality Numerical investigation of a jet in ground effect with a Fluid mechanics of dynamic stall. I - Unsteady flow p 520 A88-41096 of remotely sensed images crossflow p 485 A88-39511 concepts POSTLETHWAITE, ALAN SAE PAPER 872344] p 478 A88-37210 Fluid mechanics of dynamic stall. II - Prediction of full p 524 A88-39276 PARE, L. A., III Cool European p 485 A88-39512 Heating requirements and nonadiabatic surface effects scale characteristics POULOSE, M. M. REPETSKII, O. V. ILS glidescope evaluation of imperfect terrain for a model in the NTF cryogenic wind tunnel Numerical calculations of the natural vibrations of p 534 A88-37944 p 506 A88-39135 [AIAA PAPER 88-2044] turbomachine blades using the finite element method PARKER, DAVID H. POWERS, SHERYLL GOECKE p 523 A88-37543 Progress towards extreme attitude testing with Magnetic Flight tests of external modifications used to reduce blunt REYNOLDS, THOMAS L. Suspension and Balance Systems base drag [AIAA PAPER 88-2553] Preliminary airworthiness evaluation of the UH-60A [AIAA PAPER 88-2012] p 532 A88-37920 p 494 A88-40763 equipped with the XM-139 VOLCANO mine dispensing PARKER, R. L., JR.
The AEDC 1-foot transonic wind tunnel - A useful PRICE, BARRY L. system A flow-transfer device with nonmetallic diaphragms for [AD-A190604] research and development facility propulsion wind tunnel models Airworthiness and flight characteristics test of a ski p 531 A88-37912 AIAA PAPER 88-2001] 1 AIAA PAPER 88-20481 p 534 A88-37945 assembly for the UH-60A Black Hawk helicopter PARKS, M. p 518 N88-22895 PRIFUR. J. [AD-A1914141 A real-time aerodynamic analysis system for use in Calculation of transonic rotor noise using a frequency REYNOLDS, W. C. flight p 555 A88-38380 domain formulation Turbulent reacting flows and supersonic combustion [AIAA PAPER 88-2128] p 512 A88-38728 p 541 N88-22115 PUFFERT-MEISSNER, WOLFGANG [AD-A189690] PARLIER, CHARLES A. The transonic wind tunnel (TWB) at DFVLR, Brunswick REZNICK, STEVE Helicopter aerobatic flight - The tactical significance [AIAA PAPER 88-2190] p 502 A88-38756 (Federal Republic of Germany) Transonic Navier-Stokes computations p 502 A88-38756 strake-generated vortex interactions for a fighter-like n 539 N88-22909 [DFVLR-MITT-88-01] PARLINI, F. configuration Autoland testing - Pushing the (bottom) edge of the p 497 N88-22010 [NASA-TM-100009] envelope RHEA. DONALD C. p 511 A88-38703 [AIAA PAPER 88-2076] Development of an interactive real-time graphics system PARMENTIER, G. for the display of vehicle space positioning [AIAA PAPER 88-2167] p 536 A88-38744 Acoustic propagation in the low atmosphere.

Experimental study and modeling by the radius method QIU, CHUANREN Influence of unsteady aerodynamic forces on dynamic Development of a mobile research flight test support [ISL-CO-247/86] p 556 N88-22713 response of variable sweep aircraft p 516 N88-22245 capability
[AIAA PAPER 88-2087] PASTO, ARVID E. p 536 A88-38761 Improving the reliability of silicon nitride - A case study Development of a mobile research flight test support

R

Computerized life and reliability modelling for turboprop

p 551 N88-23220

capability

NASA-TM-1004281

research since 1981

[SAE PAPER 872315]

RIDDLE, DENNIS W.

p 506 N88-22883

p 508 A88-37186

Quiet Short-Haul Research Aircraft - A summary of flight

PATEL, M. H.

PAYNE, F. M.

delta wing

rotor blade vibration studies

p 540 A88-38316

p 515 A88-41222

p 482 A88-38377

RADIL, K. C.

transmissions

[NASA-TM-100918]

The use of smooth bending moment modes in helicopter

Visualization and wake surveys of vortical flow over a

p 514 A88-39415

SCHMIDT, WOLFGANG

Dornier 328 taking shape

PERSONAL AUTHOR INDEX	X	
RIGG, KENNETH W. T-33 aircraft demonstration of	f GPS ai	ided inertial
navigation	p 504	A88-37403
RILL, S. L.  Adaptation of flexible wind tunne flows	l walls fo	r supersonic
[AIAA PAPER 88-2039]	p 534	A88-37941
RIZK, MAGDI H.		
Optimizing advanced proper simultaneously updating flow variable parameters		esigns by and design
[AIAA PAPER 88-2532] RIZZETTA, DONALD P.	p 488	A88-40718
The numerical simulation of the Na	vier-Stok	es equations
for an F-16 configuration [AIAA PAPER 88-2507] RIZZI, A.	p 487	A88-40702
Comparison of Euler and Navier	-Stokes :	solutions for
vortex flow over a delta wing ROBBINS, JAMES E.	p 485	A88-39278
Reference trajectories from GPS		nents A88-37386
ROBBINS, ROBERT D.  Preliminary airworthiness evaluation	•	
Advanced Digital Optical Control Sy		
[AD-A190674] ROBERTS, A. SIDNEY, JR.	p 516	N88-22030
Aerodynamic investigation by infra	ared imag	ing
(AIAA PAPER 88-2523) ROBERTS, FRANKLIN D.	p 545	A88-40713
The F-15 STOL and maneuver tech (S/MTD) program	nnology d	emonstrator
(SAE PAPER 872383) ROBERTS, J. L.	p 510	A88-37232
F-15E flight test program overview [AIAA PAPER 88-2077]		1988 A88-38704
ROBERTS, L.  Estimation of thrust augmentor per applications	rformance	in V/STOL
[SAE PAPER 872323] Experimental studies of vortex flow		A88-37192
[NASA-CR-182874] ROBERTS, LEONARD	p 551	N88-23171
Navier Stokes computation of the		d over delta
wings with spanwise leading edge bit [AIAA PAPER 88-2558]		A99 40704
ROBINSON, MICHAEL C.  Pitch rate and Reynolds number	•	A88-40734
rectangular wing	enecis o	a pitching
[AIAA PAPER 88-2577] Impingement of orthogonal unstea		A88-40746 x structures
on trailing aerodynamic surfaces [AIAA PAPER 88-2580]	- 400	A88-40749
IOBINSON, W. H.  Vehicles and aircraft on floating ic	•	A86-40749
IODI, W.		A88-40066
Computational study of the unstead		ue to wakes A88-38984
OGERS, STUART E.  An upwind differencing scheme for	or the tin	ne-accurate
incompressible Navier-Stokes equating [AIAA PAPER 88-2583]		A88-40752
OHR, F. J. Corrosion-resistant thermal barrier		
OMINE, B. J.		A88-38315
Nondestructive evaluation of large components		
[AD-A190998] OSENFELD, M.		N88-22954
Numerical study of the skin frictio		
incidence OTH, A. J.		A88-38376
Development and evaluation of a		
ullage composition model. Volum determination of airplane fuel tank		
(AD-A190408)		N88-22025
OTH, KARLIN R.  Numerical simulation of a subson	ic iet in a	a crossflow

[SAE PAPER 872343]

cloud physics parameters

appropriate to circulation control airfoils

**ROTH, BOLAND** 

IESA-TT-10801

hase of a body

[NASA-TM-100090]

RUBESIN, M. W.

ROUNDS, STEPHEN F.

harmonically oscillating lift surface systems SCHNEIDER, KLAYS [ETN-88-91886] p 546 N88-22290 Evaluation of ceramic thermal barrier coatings for gas RUSAKOV, V. V. turbine engine components ETN-88-91947 p 543 N88-22998 Analytical study of friction and heat transfer in the vicinity SCHOENUNG, B. of a three-dimensional critical point at low and moderate Reynolds numbers Computational study of the unsteady flow due to wakes p 483 A88-38847 passing through a channel SCHROEDER, JEFFERY A. p 483 A88-38984 S An investigation of the ability to recover from transients following failures for single-pilot rotorcraft p 529 N88-22905 INASA-TM-1000781 SAAL, KARL W. Development and qualification of S-76B category 'A' SCHROEDER, JEFFREY A. takeoff procedure featuring variable CDP and V2 speeds Integrated control and display research for transition and vertical flight on the NASA V/STOL Research Aircraft p 511 A88-38727 [AIAA PAPER 88-2127] SADLER, G. B. The use of rule induction to assist in the diagnosis of ISAE PAPER 8723291 p 526 A88-37198 SCHULTZ, K.-J. avionic circuit board defects LETN-88-920771 p 521 N88-22899 Advancing-side directivity and retreating-side SADLER, GENE interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] 1987 Technical Committee Highlights - The year in p 556 N88-22710 p 475 A88-40558 SCIPIONI, LOUIS, JR. Allison Gas Turbine - In the forefront of vertical flight propulsion R&D p 524 A88-40563 SAILEY, RICHARD H. Inflow measurement made with a laser velocimeter on p 524 A88-40563 a helicopter model in forward flight. Volume 3: Rectangular SEINER, JOHN M. Supersonic jet plume interaction with a flat plate [SAE PAPER 872361] p 479 A88 planform blades at an advance ratio of 0.30 p 479 A88-37222 INASA-TM-1005431 p 497 N88-22015 Inflow measurements made with a laser velocimeter on SEKUNDOV, A. N. a helicopter model in forward flight. Volume 4: Tapered Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665 planform blades at an advance ratio of 0.15 p 480 A88-37665 NASA-TM-100544] p 499 N88-22863 SELLERS, WILLIAM L., III SÁKAKIBARA, SEIZÓ The Basic Aerodynamics Research Tunnel - A facility dedicated to code validation Flow quality of NAL two-dimensional transonic wind [AIAA PAPER 88-1997] tunnel. Part 1: Mach number distributions, flow angularities p 531 A88-37910 Riblet drag reduction at flight conditions [AIAA PAPER 88-2554] p 49 and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911 p 539 N88-22911 p 494 A88-40764 SEMENOV, G. R. SAMSONOV, A. L. Dependence of structure of stabilized ZrO2 coatings on Model study of thermal stresses in gas-turbine blades p 543 N88-22990 with protective coating p 542 N88-22989 condensation rate SANKAR, L. N. SENTOU, ETSUROU Structure and equipments of the T-2 CCV aircraft A comparison of numerical algorithms for unsteady p 514 A88-40530 transonic flow p 480 A88-37360 Application of Navier-Stokes analysis to stall flutter SEO, RYOZO p 530 N88-23249 Optical technology application in aircraft SARIPALLI, K. R. p 474 A88-40532 Unsteady features of jets in lift and cruise modes for SETTLES, G. S. VTOL aircraft Microprocessor control of high-speed wind tunnel [SAE PAPER 872359] p 478 A88-37220 stagnation pressure AIAA PAPER 88-2062] LDV measurements on impinging twin-jet fountain flows p 535 A88-37949 with a simulated fuselage undersurface SHAFFER, WINSTON J., II Noise assessment of unsuppressed TF-34-GE-100A p 484 A88-38986 engine at Warfield ANG, Baltimore, Maryland Experimental investigation of Hover flowfields in water p 556 N88-22702 at the McDonnell Douglas Research Laboratories LAD-A1899661 SHAMMA, JEFF S. n 549 N88-23135 SATO, MAMORU Analysis and design of gain scheduled control Flow quality of NAL two-dimensional transonic wind systems tunnel. Part 1: Mach number distributions, flow angularities [NASA-CR-182867] p 529 N88-22904 and preliminary study of side wall boundary layer suction SHANG, JOSEPH J. S. INASA-TT-202091 p 539 N88-22911 The numerical simulation of the Navier-Stokes equations SATTA, ANTONIO for an F-16 configuration [AIAA PAPER 88-2507] The use of optimization technique and through flow p 487 A88-40702 analysis for the design of axial flow compressor stages SHAUGHNESSY, JOHN D. A description of an automated database comparison p 477 A88-37112 SAUNDERS, D. S. program Effect of load duration on the fatigue behaviour of [NASA-TM-100609] p 554 N88-23463 SHAWLER, WENDELL H. graphite/epoxy laminates containing delaminations p 541 A88-40174 T-46A final report [AIAA PAPER 88-2092] SAVAGE, M. p 511 A88-38709 SHEN, C. Q. Computerized life and reliability modelling for turboprop transmissions Measurements of aerodynamic forces on unsteadily [NASA-TM-100918] moving bluff parachute canopies p 551 N88-23220 p 549 N88-23137 SAWADA, KEISUKE SHEN, MENGYU Numerical simulation of compressible flow field about Mixed direct-inverse problem of transonic cascade complete ASKA aircraft configuration p 498 N88-22244 [SAE PAPER 872346] p 478 A88-37212 SHEN, ZHEN SCHEIMAN, J. Behaviour of damage tolerance of composite aircraft Laser velocimeter measurements in a wing-fuselage type structures p 544 A88-38187 iuncture SHENKER, MARTIN [NASA-TM-100588] p 497 N88-22012 Optical design criteria for binocular helmet-mounted SCHICKEL, KLAUS-PETER p 478 A88-37209 displays p 520 A88-41366 Bibliography of icing on aircraft (status 1987) [DFVLR-MITT-87-18] p 502 N SHENOY, RAJARAMA K. p 502 N88-22876 Standardized ice accretion thickness as a function of 1987 Technical Committee Highlights - The year in review p 475 A88-40558 Visualization and wake surveys of vortical flow over p 553 N88-23346 Acoustic characteristics of 1/20-scale model helicopter delta wing p 482 A88-38377 rotors SCHILLING, L. J. A fully integrated GPS/Doppler/inertial navigation [NASA-CR-177355] p 557 N88-23548 The NASA Integrated Test Facility and its impact on p 504 A88-37400 SHERIDAN, ARTHUR E. flight research [AIAA PAPER 88-2095] Configuration E-7 supersonic STOVL fighter/attack p 535 A88-38711 Separation of a supersonic boundary layer ahead of the SCHLOSSER, KEVIN C. technology program [SAE PAPER 872379] p 480 A88-37697 A GPS hover position sensing system p 509 A88-37229 p 503 A88-37390 SHIBATA, KATSUHEI On the validation of a code and a turbulence model Flight testing results of T-2 CCV p 528 A88-40529 SCHMIDT, M. C. Flow in out-of-plane double S-bends SHIGETO, TAKEAKI p 499 N88-22864 p 484 A88-39011 Flat panel display trends p 545 A88-40535

RUIZCALAVERA, LUIS P.

A panel method based on velocity potential to compute

p 477 A88-37180

p 482 A88-38343

Flow analysis around aircraft by viscous flow

computation

p 508 A88-37186

Effect of ground proximity on the aerodynamic characteristics of the STOL aircraft

STEWART, VEARL R.

ISAE PAPER 8723081

analysis

p 526 N88-23247

Numerical analysis of multiple element high lift devices

by Navier Stokes equation using implicit TVD finite volume

SHIMA, EIJI

[AIAA PAPER 88-2574] p 491 A88-40743	Detection of large-scale organized motions in a turbulent	STINEBRING, D. R.
SHIMIZU, MIHO	boundary layer p 484 A88-39023	Experimental investigation of a jet impinging on a ground plane in the presence of a cross flow
Flow analysis around aircraft by viscous flow	SNOWDON, ERNIE R.  Flight testing at the West Coast Offshore Operating	[SAE PAPER 872326] p 478 A88-37195
computation p 482 A88-38343	Area	STOJICH, R.
SHIVARAM, MALUR R.	[AIAA PAPER 88-2150] p 536 A88-38740	Decentralized approach to the design of automatic flight
A survey of the flight testing and evaluation of CF M56	SOBIECZKY, H.	control systems p 528 A88-40858
series turbofan LAIAA PAPER 88-2078 l p 513 A88-38763	Interactive geometry definition and grid generation for	STONE, L. S.
1,	applied aerodynamics	Radarbet - A multiple trajectory estimator using an expert
SHKANOV, I. N.	[AIAA PAPER 88-2515] p 554 A88-40707	system
Life of gas turbine engine disks with cracks	SODERMAN, PAUL T.	[AIAA PAPER 88-2082] p 505 A88-38705
·	Aerodynamic flow quality and acoustic characteristics	STONUM, RONALD K.
SHLIANNIKOV, V. N.  Life of gas turbine engine disks with cracks	of the 40- by 80-foot test section circuit of the National	Wave drag and high-speed performance of supersonic
p 544 A88-37549	Full-Scale Aerodynamic Complex ISAF PAPER 8723281 p 530 A88-37197	STOVL fighter configurations
SHVETS, ALEKSANDR IVANOVICH	(energy energy)	[SAE PAPER 872311] p 479 A88-37235
Aerodynamics of supersonic shapes	SOLTANI, M. R.	STRGANAC, THOMAS W.
p 486 A88-40311	Experimental measurements on an oscillating 70-degree	A study of aeroelastic stability for the model support
SIEBECKER, HANS	delta wing in subsonic flow [AIAA PAPER 88-2576] p 491 A88-40745	system of the National Transonic Facility [AIAA PAPER 88-2033] p 533 A88-37936
Method and device for the detection and identification		
of a helicopter	SOSNOVSKII, ANDREI ANAN'EVICH Radio-electronic equipment of aircraft: Handbook	A numerical model of unsteady, subsonic aeroelastic
[NASA-TT-20251] p 556 N88-22698	p 505 A88-37699	behavior (NASA-TM-101126) p 499 N88-22862
SIEBERSMA, TIMOTHY	SOTOMAYER, W. A.	(1
Computational simulation of vortex generator effects on	A comparison of numerical algorithms for unsteady	SUEOKA, AKIRA  Development of fiber optic data bus for aircraft
transonic shock/boundary layer interaction	transonic flow p 480 A88-37360	p 555 A88-38344
[AIAA PAPER 88-2590] p 495 A88-40771	SOVA, G. J.	•
SIEMENS, WERNER	Application of Navier-Stokes analysis to predict the	SULLY, P. R.  The synthesis of ejector lift/vectored thrust for STOVL
Comparison of different kinds of compact crossflow heat	internal performance of thrust vectoring two-dimensional	[SAE PAPER 872378] p 523 A88-37228
exchangers	convergent-divergent nozzles	SUMICH, MARK
[ESA-TT-1076] p 550 N88-23169	[AIAA PAPER 88-2586] p 493 A88-40755	The RSRA/X-Wing experiment - A status report
SIEVERS, G. KEITH	SPADAFORA, STEPHEN J.	[SAE PAPER 872371] p 479 A88-37225
NASA advanced turboprop research and concept	Development of a high-temperature resistant (700 F),	SWEETMAN, BILL
validation program LNASA-TM-100891   p 526 N88-22902	corrosion-preventive organic coating	X-31 - Through the grape barrier p 515 A88-41250
(miles)	[AD-A191407] p 543 N88-23009	SWESEY, J. R.
SILER, LEO G. On hypersonic transition testing and prediction	SPAID, FRANK W.	Turbine fuels from tar sands bitumen and heavy oil.
[AIAA PAPER 88-2007] p 532 A88-37916	Boundary-layer and wake measurements on a swept,	Volume 2, phase 3: Process design specifications for a
SIMPSON, R. L.	circulation-control wing FNASA-TM-894261 p 497 N88-22013	turbine fuel refinery charging San Ardo heavy crude oil
Time-dependent structure in wing-body junction flows	(14.16.1 1.11.00 1.20)	[AD-A190120] p 543 N88-23011
p 484 A88-38988	SPENCER, D. A.	SZECSODY, ALEX J.
SINCLAIR, D. W.	Aeroacoustics of advanced STOVL aircraft plumes [SAE PAPER 872358] p 554 A88-37219	Aircraft noise at the Grand Canyon National Park,
Calculated viscous effects on airfoils at transonic	(	Arizona, USA p 552 A88-39729
speeds (AIAA PAPER 88-2027) p 481 A88-37931	SPINA, E. F.  Detection of large-scale organized motions in a turbulent	SZODRUCH, J.
[,	boundary layer p 484 A88-39023	Piezo-electric foils as a means of sensing unsteady
SINGER, S. W.	boundary layer pro-	surface forces on flow-around bodies
Applications of an Fuler aerodynamic method to	CDI ETTETOESSER W R	0.493 488-38976
Applications of an Euler aerodynamic method to	SPLETTSTOESSER, W. R. Advancing-side directivity and retreating-side	p 483 A88-38976
free-vortex flow simulation	Advancing-side directivity and retreating-side	_
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708 SINGH. G. S.	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise	p 483 A88-38976
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710	_
free-vortex flow simulation [A/AA PAPER 88-2517] p 487 A88-40708  SINGH, G. S. On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710 SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials	т
free-vortex flow simulation [A/AA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710 SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials	т
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710 SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327 SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066 SRINIVASAN, GANAPATHI R.	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528 TAKAHASHI, FUMIYUKI
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] TAKANASHI, SUSUMU
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA. R.	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN. WOLFGANG	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATH R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system  [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, J. P.	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil.
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development  development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (INAS-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NAS-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (INAS-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system  [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120]  TAN, ANYHONG
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system  [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMTH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120]  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23120  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120]  TAN, ANYHONG
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system  [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-102892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23120  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system  [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NAS-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical valuation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-2118] p 551 A88-38719	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight  p 540 A88-39419	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-2118] p 511 A88-38719  Determination of the aerodynamic characteristics of the	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (INAS-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight  p 540 A88-39419  STEPANOV, N. V.  Life of gas turbine engine disks with cracks	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves p 486 A88-40375
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-2118] p 511 A88-38719  Determination of the aerodynamic characteristics of the Mission Adaptive Wing	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight  p 540 A88-39419  STEPANOV, N. V.  Life of gas turbine engine disks with cracks p 544 A88-37549	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 87-2346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NAS-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  TANAKA, KEJI First flight simulator test of the head-up display for NAL OSTOL experimental aircraft (ASUKA)
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126  Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-2118] p 511 A88-38719  Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight  p 540 A88-39419  STEPANOV, N. V.  Life of gas turbine engine disks with cracks p 544 A88-37549  STETSON, KENNETH F.	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  P 486 A88-40375  TANAKA, KEIJI First flight simulator test of the head-up display for NAL OSTOL experimental aircraft (ASUKA) [DE88-751804] p 521 N88-22896
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-2118] p 511 A88-38719  Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733  SMITH, STEVE  Developing a wide field of view HMD for simulators	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight  STEPANOV, N. V.  Life of gas turbine engine disks with cracks p 544 A88-37549  STETSON, KENNETH F.  On hypersonic transition testing and prediction	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  P 486 A88-40375  TANAKA, KEIJI First flight simulator test of the head-up display for NAL OSTOL experimental aircraft (ASUKA) [DE88-751804] p 521 N88-22896 Basic design of a flight director system for NAL STOL
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack  p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL  Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-256] p 489 A88-40733  SMITH, STEVE  Developing a wide field of view HMD for simulators p 520 A88-41367	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (INAS-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight  P 540 A88-39419  STEPANOV, N. V.  Life of gas turbine engine disks with cracks p 544 A88-37549  STETSON, KENNETH F.  On hypersonic transition testing and prediction [AIAA PAPER 88-2007] p 532 A88-37916	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NAS-TT-20209] p 539 N88-22911  TAKEKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23911  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  P 486 A88-40421  TANAKA, KEJI First flight simulator test of the head-up display for NAL OSTOL experimental aircraft (ASUKA) [DE88-751804] Basic design of a flight director system for NAL STOL research aircraft
free-vortex flow simulation [AIAA PAPER 88-2517] p 487 A88-40708  SINGH, G. S.  On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269  SKOW, ANDREW M.  Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130  SLEDJESKI, L. A.  Radarbet - A multiple trajectory estimator using an expert system [AIAA PAPER 88-2082] p 505 A88-38705  SLEMROD, MARSHALL Problems in nonlinear continuum dynamics [AD-A190538] p 554 N88-22691  SMASHEY, R. W.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SMIRNOVA, I. P.  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  SMITH, M. K.  Analytical sensor redundancy assessment [NASA-CR-182892] p 521 N88-22901  SMITH, RICHARD A.  Analytical evaluation of birdstrike against a F-16A laminated canopy [AIAA PAPER 88-2268] p 514 A88-40868  SMITH, STEPHEN B.  AFTI/F-111 Mission Adaptive Wing flight research program [AIAA PAPER 88-2118] p 511 A88-38719  Determination of the aerodynamic characteristics of the Mission Adaptive Wing [AIAA PAPER 88-2556] p 489 A88-40733  SMITH, STEVE  Developing a wide field of view HMD for simulators	Advancing-side directivity and retreating-side interactions of model rotor blade-vortex interaction noise (NASA-TP-2784) p 556 N88-22710  SPRAGUE, R. A.  The role of electron microscopy in gas turbine materials development p 545 A88-40327  SQUIRE, V. A.  Vehicles and aircraft on floating ice p 536 A88-40066  SRINIVASAN, GANAPATHI R.  Tip vortices of isolated wings and helicopter rotor blades [AD-A191336] p 501 N88-22874  SRIVASTAVA, R.  Application of Navier-Stokes analysis to stall flutter p 530 N88-23249  STAEUDLIN, WOLFGANG  CFRP landing flaps for the Airbus A320 p 474 A88-39416  STARR, R. F., JR.  Study on needs for a magnetic suspension system operating with a transonic wind tunnel [AIAA PAPER 88-2014] p 533 A88-37922  STEFKO, GEORGE L.  Porous wind tunnel corrections for counterrotation propeller testing [NASA-TM-100873] p 498 N88-22019  STEGER, J. L.  Numerical investigation of a jet in ground effect with a crossflow [SAE PAPER 872344] p 478 A88-37210  STEINHEIL, ECKART  Technologies for hypersonic flight  STEPANOV, N. V.  Life of gas turbine engine disks with cracks p 544 A88-37549  STETSON, KENNETH F.  On hypersonic transition testing and prediction	TAKAHAMA, MORIO FBW system and control law of the T-2 CCV p 528 A88-40528  TAKAHASHI, FUMIYUKI Flow past two-dimensional ribbon parachute models [AIAA PAPER 88-2524] p 488 A88-40714  TAKANASHI, SUSUMU Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212  TAKASHIMA, KAZUAKI Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction [NASA-TT-20209] p 539 N88-22911  TAKKOSHI, AKIHIRO Development overview of the T-2 CCV p 528 A88-40527  TALBOT, A. F. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a turbine fuel refinery charging San Ardo heavy crude oil [AD-A190120] p 543 N88-23011  TAN, ANZHONG Unsteady aerodynamic heating phenomena in the interaction of shock wave/turbulent boundary layer p 486 A88-40421  TANAHASHI, YOSHIHARU Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves  P 486 A88-40375  TANAKA, KEIJI First flight simulator test of the head-up display for NAL OSTOL experimental aircraft (ASUKA) [DE88-751804] p 521 N88-22896 Basic design of a flight director system for NAL STOL

research since 1981

(SAE PAPER 872315)

SMITH, TODD E.

SMITS, A. J.

Aeroelastic turbomachinery

forced

response

Stability and control methodology for conceptual aircraft

p 530 N88-22906

design. Volume 1: Methodology manual [AD-A191314]

TASKER, FREDERICK A.

Assessment of transient testing techniques for rotor stability testing [AIAA PAPER 88-2401]

p 546 A88-40871

Estimation of thrust augmentor performance in V/STOL applications

[SAE PAPER 872323] TAVELLA, DOMINGO A. p 522 A88-37192

Navier Stokes computation of the flow field over delta wings with spanwise leading edge blowing

p 489 A88-40734 [AIAA PAPER 88-2558] TAYLOR, NORMA F.

Impact pressure error on the EC-18B subsonic aircraft [AIAA PAPER 88-2177] p 513 A88-38748 TAZARTES D. A.

Integration of GPS receivers into existing inertial navigation systems p 504 A88-37399 TENHAVE, A. A.

Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p 517 N88-22887

TERPSTRA, JAMES E.

Airborne data bases - A quiet revolution p 506 A88-41089

**TESKE, REINER** 

New structural technologies for the Dornier 328 p 473 A88-37297 fuselage

THELEN, GREGORY L.

Linear state space modeling of a turbofan engine p 524 N88-22035 [AD-A190110]

THOMAS, DAVID M.

Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system

[AD-A190614] p 529 N88-22042 THOMPSON, ELTON R.

On hypersonic transition testing and prediction [AIAA PAPER 88-2007] p 532 A86 p 532 A88-37916

THOMPSON, R. L.

Life assessment of combustor liner using unified p 525 N88-22384 constitutive models

TICHY, JIRI

NOISE-CON 87; Proceedings of the National Conference on Noise Control Engineering, Pennsylvania State University, State College, June 8-10, 1987 p 555 A88-39701

TICKNER, A. T.

A role for fibre optics in antenna measurements

p 544 A88-38116

TISCHLER MARK B.

Using frequency-domain methods to identify XV-15 p 510 A88-37234 (SAE PAPER 8723851

TIWARI, ANIL

TJALSMA, C. R.

Differential GPS with a sequencing receiver p 505 A88-37406

Development of a flexible and economic helicopter engine monitoring system p 517 N88-22887

TOBAK, MURRAY

Bifurcations in unsteady aerodynamics-implications for testing

[NASA-TM-100083]

p 497 N88-22014

TONG, M. T.

Life assessment of combustor liner using unified constitutive models p 525 N88-22384

TORENBEEK, E.

The initial calculation of range and mission fuel during conceptual design

p 517 N88-22889

TRAMPNAU, U.

A millimeter-wave low-range radar altimeter for

helicopter applications - Experimental results p 519 A88-39496

TREASTER, A. L.

Experimental investigation of a jet impinging on a ground plane in the presence of a cross flow p 478 A88-37195

[SAE PAPER 872326] TRETYACHENKO, G. N.

Model study of thermal stresses in gas-turbine blades

with protective coating p 542 N88-22989 TRIMPI, ROBERT L. Unexpected/expected results from the Langley 20-Inch

Supersonic Wind Tunnel during initial checkout [AIAA PAPER 88-1999] p 531 A88-37911

TROFIMENKO, A. A.

Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990

TROUTT, TIMOTHY R.

Unsteady aerodynamic forces at low airfoil pitching rates

[AIAA PAPER 88-2579] p 492 A88-40748 TRUECK, BEATE

Evaluation of ceramic thermal barrier coatings for gas turbine engine components [ETN-88-91947] p 543 N88-22998

TRUJILLO ANDERSON, BIANCA

Techniques used in the F-14 variable-sweep transition flight experiment p 513 A88-38762

[AIAA PAPER 88-2110] TSUJIMOTO, TAKASHI

Stability and control augmentation system of 'ASKA' [SAE PAPER 872334] p 527 A88-37203

TURKEL, ELI

Accuracy versus convergence rates for a three dimensional multistage Euler code INASA-CR-1816651 p 554 N88-23519

UHSE, WOLFGANG

Technologies for hypersonic flight

p 540 A88-39419

p 478 A88-37210

V.D.KWAAK, D. W.

Reliability analysis within a Computer Aided Engineering (CAE) infrastructure

NLR-MP-86059-U] p 547 N88-22369 VACHERLON, J. F.

GPS phase III multi-channel user equipment

p 503 A88-37378 VALANTE, A.

Rapid prototyping of complex avionics system architectures p 521 N88-22898

IETN-88-922751 VAN BLARICUM, T. J.

Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations p 541 A88-40174

VAN DALSEM, W. R. Numerical investigation of a jet in ground effect with a

ISAE PAPER 8723441

VAN DIERENDONCK, A. J. A digital P-code GPS reciever and its applications to

embedded systems p 503 A88-37393 VANATTA, NICHOLAS C.

AQM-127A full scale engineering development Flight Test Program

[AIAA PAPER 88-2121] p 511 A88-38722

VANDERVELDEN, ALEXANDER J. M.

Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891

VANDERVOOREN, J.

Trends in Computational Fluid Dynamics (CFD) for eronautical 3D steady applications: The Dutch situation INI R-MP-86074-U1 p 498 N88-22017

VANDERWEES, A. J.

Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017

VANGELDER P. A.

Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038

Experimental investigation of Hover flowfields in water at the McDonnell Douglas Research Laboratories

p 549 N88-23135

VASANTHA, R. Unsteady

nonsimilar laminar compressible boundary-layer flow over a yawed infinite circular p 495 A88-40970 cylinder

VAUGHN, VAL D.

Flight test imagery - Getting more for less [AIAA PAPER 88-2102] p 505 p 505 A88-38714

VÈLDMAN, A. E. P.

Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017

VELEZ, JULIO E.

Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive controller

(AD-A189848)

p 529 N88-22040

VEMURU, C. S.

Design of low Reynolds number airfoils. I [AIAA PAPER 88-2572] p 494 A88-40765

VERHAAGEN, NICK G.

Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737

VERHOFF, VINCENT G.

Small engine components test facility turbine testing

[NASA-TM-100887] p 525 N88-22037

VERMOREL, J.

Acoustic propagation in the low atmosphere. Experimental study and modeling by the radius method p 556 N88-22713 VIEGAS, J. R.
On the validation of a code and a turbulence model

appropriate to circulation control airfoils

p 499 N88-22864 [NASA-TM-100090] VIKEN, JEFFREY K.

Boundary-layer stability analysis of NLF and LFC experimental data at subsonic and transonic speeds SAE PAPER 871859] p 483 A88-38925

VOERSMANN, P. METEOPOD, an airborne system for measurements of

mean wind, turbulence, and other meteorological

[AIAA PAPER 88-2103] p 519 A88-38715 An airborne realtime data processing and monitoring

system for research aircraft [AIAA PAPER 88-2165] p 506 A88-38743

VON LAVANTE, E. Calculations of three-dimensional flows using the

isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762

VOROTNIKOV, P. P.

Turbulent friction on a delta wing p 480 A88-37657 VUKOBRATOVICH, M.

Decentralized approach to the design of automatic flight control systems p 528 A88-40858

WAGGONER, EDGAR G.

A transonic wind tunnel wall interference prediction

[AIAA PAPER 88-2538] p 537 A88-40722 WAGNER, C. A.

The NASA Integrated Test Facility and its impact on flight research

p 535 A88-38711

[AIAA PAPER 88-2095] WAGNER, CHARLES A.

Effects of update and refresh rates on flight simulation visual displays

[NASA-TM-100415] p 516 N88-22033 WALKER, JOHN M. Impingement of orthogonal unsteady vortex structures

on trailing aerodynamic surfaces

[AIAA PAPER 88-2580] p 492 A88-40749 WALLACE, H. W. Propulsion and airframe aerodynamic interactions of

supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 WALSH, JOANNE L.

Minimum weight design of rotorcraft blades with multiple frequency and stress constraints p 517 N88-22892 INASA-TM-1005691

WALSH, KEVIN R.

Performance improvements of an F-15 airplane with an integrated engine-flight control system
[AIAA PAPER 88-2175] p 527 A88-38747

WALSH, MICHAEL J.

Riblet drag reduction at flight conditions p 494 A88-40764 [AIAA PAPER 88-2554]

WALTERS M M

Experimental investigation of a jet impinging on a ground plane in the presence of a cross flow

p 478 A88-37195 [SAE PAPER 872326] WANG, PEIDE

Numerical calculations of a class of optimal flight p 553 A88-38178

WANG, YI-YUN

Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil p 482 A88-38303

WARD, DONALD T.

Nonintrusive measurements of vortex flows on delta wings in a water tunnel p 493 A88-40760

[AIAA PAPER 88-2595] WASSUM, DONALD L.

Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel

[NASA-TM-100529] p 497 N88-22016 WEDEMEYER, E. The use of 2-D adaptive wall test sections for 3-D

[AIAA PAPER 88-2041] WEDEN, GILBERT J.

flows

An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554

p 534 A88-37943

WEICKMANN, ANN An interactive method for modifying numerical model p 552 A88-38679 vind forecasts WEIMER, JOSEPH A. Control of an aircraft electric fuel pump drive p 524 A88-39133 WEINBERG, S.

A plan for coupling wind tunnel testing with CFD [AIAA PAPER 88-1996] p 531 A88-37909

WEISROSE, S.

IR group activities at the Israel Aircraft Industries p 474 A88-40386

WEISS, JEROLD L. Expanded envelope concepts for control-element failure detection and identification aircraft p 507 N88-22886 [NASA-CR-181664]

The ONERA water tunnels test possibilities for flow visualization in aeronautical and Naval domains p 550 N88-23139

WESTCOTT, D. C. A digital P-code GPS reciever and its applications to p 503 A88-37393 embedded systems WESTPHAL, GUSTAV

Avionics for transport aircraft - Current development p 520 A88-41098 status

WESTPHAL, KLAUS-G. propagation multipath Measurement of electromagnetic waves in actual airport environments

p 506 A88-39813 WHITELAW, J. H.

Flow in out-of-plane double S-bends p 484 A88-39011

WHITFIELD, DAVID L. Three-dimensional unsteady transonic viscous-inviscid interaction using the Euler and boundary-layer equations p 491 A88-40747 [AIAA PAPER 88-2578]

WHITLOW, JOHN B., JR. NASA advanced turboprop research and concept validation program p 526 N88-22902 INASA-TM-1008911

WHITMORE, STEPHEN A.

Formulaton of a general technique for predicting pneumatic attenuation errors in airborne pressure sensing [AIAA PAPER 88-2085] p 518 A88-38707

WHITTLEY, D. C. The synthesis of ejector lift/vectored thrust for STOVL

p 523 A88-37228 [SAE PAPER 872378] WICKENS, R. H.

The use of the NRC/NAE water facilities in Canadian aeronautical research and development

p 539 N88-23132

WILCOX, FLOYD J., JR. Unexpected/expected results from the Langley 20-Inch Supersonic Wind Tunnel during initial checkout p 531 A88-37911 [AIAA PAPER 88-1999]

WILDER, BRENDAN L. A study of damage tolerance in curved composite panels

p 541 N88-22092 [AD-A1906171 WILLIAMS, G. C.

V/STOL and the Royal Air Force [SAE PAPER 872319] p 508 A88-37189 WILLIAMS, MARC H.

The 2-D and 3-D time marching transonic potential flow p 501 N88-23245 method for propfans WILSON, D. R.

Correlation of entrainment and lift enhancement for a two-dimensional propulsive wing [SAE PAPER 872325] p 477 A88-37194

WILSON, DONALD R. Development of the University of Texas at Arlington Aerodynamics Research Center p 531 A88-37913 [AIAA PAPER 88-2002]

WILSON, SAMUEL Impact of bypass ratio on thrust-to-weight for V/STOL [SAE PAPER 872348] p 523 A88-37237 p 523 A88-37237

WIMMER, JIM

Gas turbines challenge ceramic technology p 540 A88-37430 WINBORN, B. R.

Correlation of entrainment and lift enhancement for a two-dimensional propulsive wing p 477 A88-37194 [SAE PAPER 872325] WISSLER, JOHN B.

Pitch rate and Reynolds number effects on a pitching rectangular wing p 491 A88-40746 [AIAA PAPER 88-2577]

WITTEN, A. J. Investigation of aeroacoustic mechanisms by remote thermal imaging IDE88-0026121 p 538 N88-22046

WITTENBERG, K. ROBYN

Grid generation and flow analyses for wing/body/winglet configurations p 489 A88-40730

[AIAA PAPER 88-2548] WITTLIN GIL

KRASH parametric sensitivity study: Transport category AD-A1899621 p 515 N88-22024

WLEZIEN, R. W. Unsteady features of jets in lift and cruise modes for VTOL aircraft

[SAE PAPER 872359] p 478 A88-37220 WOAN, CHUNG-JIN

Transonic Euler calculations of a wing-body configuration using a high-accuracy TVD scheme p 488 A88-40729

[AIAA PAPER 88-2547] WOLF, RICHARD K. Estimation of turbulence effects on sound propagation

p 555 A88-39712 from low flying aircraft WOLF, STEPHEN W. D. Highlights of experience with a flexible walled test

section in the NASA Langley 0.3-meter transonic cryogenic

[AIAA PAPER 88-2036] p 533 A88-37938 WOLFFELT, KARL W.

Investigation on the movement of vortex burst position with dynamically changing angle of attack for a schematic deltawing in a watertunnel with correlation to similar studies in windtunnel p 550 N88-23152

WOLFSHTEIN, M. Numerical study of the skin friction on a spheroid at p 482 A88-38376 incidence

WOLLASTON, JAMES W. VSTOL design implications for tactical transports p 473 A88-37206 [SAE PAPER 872338]

WU. J. C. Application of Navier-Stokes analysis to stall flutter p 530 N88-23249

WYGNANSKI, I, J. Experimental investigation of a spanwise forced mixing

p 496 N88-22007 [AD-A190136] WYLIE, DONALD

An interactive method for modifying numerical model p 552 A88-38679 wind forecasts

VAMADA HIDEJIRO

Development overview of the T-2 CCV p 528 A88-40527

VAMAMOTO, SUSUMU Aircraft observation of the specific humidity and process

of the water vapor transfer in the upper mixed boundary p 552 A88-39508 YAMASHITA, AKIRA

Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves

p 486 A88-40375 YAMATO, HIROYUKI

Flight test of the Japanese USB STOL experimental aircraft ASKA p 513 A88-38750 AIAA PAPER 88-2180] YAN. MING

Influence of unsteady aerodynamic forces on dynamic esponse of variable sweep aircraft p 516 N88-22245

CSCM Navier-Stokes thermal/aerodynamic analysis of hypersonic nozzle flows with slot injection and wall cooling
[AIAA PAPER 88-2587]

p 493 A88-40756 YÂNG, XIN Linear dynamics of supersonic inlet

p 482 A88-38186

YANG, Z. C.

Analysis of limit cycle flutter of an airfoil in incompressible p 546 A88-41219 flow YASUE, MASAHIRO

FBW system and control law of the T-2 CCV p 528 A88-40528

YAZAWA, KENJI First flight simulator test of the head-up display for NAL

QSTOL experimental aircraft (ASUKA) p 521 N88-22896 [DE88-751804] YEATON, ROBERT B.

Boundary-layer stability analysis of NLF and LFC experimental data at subsonic and transonic speeds p 483 A88-38925 [SAE PAPER 871859] YEH. DAVID T.

Navier Stokes computation of the flow field over delta wings with spanwise leading edge blowing p 489 A88-40734 [AIAA PAPER 88-2558]

YIANNESKIS, M. Flow in out-of-plane double S-bends

p 484 A88-39011

YOAV, Y.

IR group activities at the Israel Aircraft Industries p 474 A88-40386

YOKOTA, MASAHIKO

Optical technology application in aircraft p 474 A88-40532

YOKOYAMA, OSAYUKI

Aircraft observation of the specific humidity and process of the water vapor transfer in the upper mixed boundary p 552 A88-39508 laver

YOSHIHARA, H.

PNS calculations of hypersonic transitional flow over cones

[AIAA PAPER 88-2565] p 490 A88-40738 YÙ, N. JONG

Grid generation and flow analyses for wing/body/winglet configurations

p 489 A88-40730 [AIAA PAPER 88-2548]

Z

ZELL, PETER T.

Aerodynamic flow quality and acoustic characteristics of the 40- by 80-foot test section circuit of the National Full-Scale Aerodynamic Complex p 530 A88-37197

[SAE PAPER 872328] ZHAO, L. C.

Analysis of limit cycle flutter of an airfoil in incompressible p 546 A88-41219

ZHAO, ZHENYAN The modelling technique of the flight system in flight p 553 A88-38179 simulator

ZHELANNIKOV, A. I. Computer simulation of turbulent jets and wakes

p 544 A88-37661

ZHOU, MINXUAN Experimental investigation on rigid hollow hemispherical

parachute model in accelerating and steady flow p 482 A88-38185

ZHU. DEPEI Some aspects of the reliability analysis of aircraft ructures p 544 A88-38181

structures

Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel test pressure data report

[NASA-CR-177343-VOL-1] n 500 N88-22866 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report [NASA-CR-177343-VOL-2]

p 500 N88-22867 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 p 500 N88-22868

ZNATY, E. Development of a variational method for chemical kinetic p 541 A88-38490 sensitivity analysis ZOZULYA, V. B.

Control of laminar flow around of the wing in free-air conditions

p 495 N88-22004 [AD-A187479] ZÚCCO, E. Rapid prototyping of complex avionics system

architectures p 521 N88-22898 1ETN-88-922751 ZÚK. JOHN

Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226

ZUO, PEI CHU The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China

p 534 A88-37942 [AIAA PAPER 88-2040] ZYSINA-MOLOZHEN, L. M. Factors affecting the temperature state of the blading

p 486 A88-40314

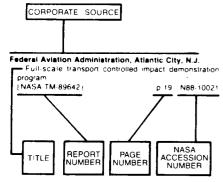
of high-temperature turbines

# **CORPORATE SOURCE INDEX**

# AERONAUTICAL ENGINEERING / A Continuing Bibliography (Supplement 230)

September 1988

# Typical Corporate Source Index Listing



Listings in this index are arranged alphabetically by corporate source. The title of the document is used to provide a brief description of the subject matter. The page number and the accession number are included in each entry to assist the user in locating the abstract in the abstract section. If applicable, a report number is also included as an aid in identifying the document.

### Aeritalia S.p.A., Turin (Italy).

Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment

[ETN-88-92274] p 557 N88-22821

Rapid prototyping of complex avionics system p 521 N88-22898 IETN-88-922751

### Aerodynamische Versuchsanstalt, Goettingen (West Germany).

An experimental investigation of flowfield about a multielement airfoil

p 481 A88-37937 IAIAA PAPER 88-20351

Aeronautical Research Inst. of Sweden, Stockholm. In-service measurements of SAAB SF-340 landing gear

[FFA-TN-1987-48]

### Air Force Center for Studies and Analyses, Washington, D.C.

Wave drag and high-speed performance of supersonic STOVL fighter configurations [SAE PAPER 872311] p 479 A88-37235

Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.

Model selection for the multiple model adaptive algorithm for in-flight simulation

[AD-A189715] p 515 N88-22022 Linear state space modeling of a turbofan engine

[AD-A190110] p 524 N88-22035

Application of eigenstructure assignment techniques in the design of a longitudinal flight control system p 528 N88-22039

Multivariable control law design for the AFTI/F-16 with a failed control surface using a parameter-adaptive

[AD-A189848] p 529 N88-22040 Kalman filter residual expert system

[AD-A190520] p 529 N88-22041

Subharmonic aliasing and its effects on the AFTI/F-16 digital flight control system

[AD-A190614] p 529 N88-22042 Geometric modeling of flight information for graphical cockpit display

IAD-A1904841 p 537 N88-22043 Multiple model parameter adaptive control for in-flight simulation

[AD-A190568] p 537 N88-22044 A study of damage tolerance in curved composite

AD-A1906171 p 541 N88-22092 Experimental comparison of lightning simulation CV-580 airborne techniques to lightning strike

[AD-A190576] p 552 N88-22496 A study of failure characteristics in thermoplastic composite material [AD-A190613] p 542 N88-22940

### Air Force Occupational and Environmental Health Lab., Brooks AFB, Tex.

Noise assessment of unsuppressed TF-34-GF-100A engine at Warfield ANG, Baltimore, Maryland p 556 N88-22702 [AD-A189966]

### Air Force Systems Command, Wright-Patterson AFB, Ohio.

Control of laminar flow around of the wing in free-air conditions IAD-A1874791 p 495 N88-22004

# Air Force Wright Aeronautical Labs., Wright-Patterson

Stability and control methodology for conceptual aircraft design. Volume 1: Methodology manual

p 530 N88-22906 [AD-A191314]

### Alphatech, Inc., Burlington, Mass.

Expanded envelope concepts aircraft control-element failure detection and identification [NASA-CR-181664] p 507 N88-22886

Analytical Services and Materials, Inc., Hampton, Va. Boundary-layer stability analysis of NLF and LFC experimental data at subsonic and transonic speeds [SAE PAPER 871859] p 483 A88-38925

Computational validation of a parabolized Navier-Stokes solver on a sharp-nose cone at hypersonic speeds TAIAA PAPER 88-25661 p 490 A88-40739 Design of low Reynolds number airfoils. I

[AIAA PAPER 88-2572] p 494 A88-40765 Arizona Univ., Tucson.

Experimental investigation of a spanwise forced mixing [ÁD-A190136] p 496 N88-22007

### Army Aviation Engineering Flight Activity, Edwards AFB. Calif.

Preliminary airworthiness evaluation of the UH-60A equipped with the XM-139 VOLCANO mine dispensing

p 516 N88-22029 Preliminary airworthiness evaluation of the UH-60A with

Advanced Digital Optical Control System (ADOCS) IAD-A1906741 p 516 N88-22030

Airworthiness and flight characteristics test of a ski assembly for the UH-60A Black Hawk helicopter [AD-A191414] p 518 N88-22895

### Army Aviation Research and Development Command, Hampton, Va.

Measurement of leading edge vortices from a delta wing using a three component laser velocimeter p 544 A88-37929 [AIAA PAPER 88-2024]

### Army Aviation Research and Development Command, Moffett Field, Calif.

Integrated control and display research for transition and vertical flight on the NASA V/STOL Research Aircraft

(SAE PAPER 872329) p 526 A88-37198 Using frequency-domain methods to identify XV-15

aeroelastic modes (SAE PAPER 872385) p 510 A88-37234

### Army Aviation Systems Command, Cleveland, Ohio. Piezoelectric pushers for active vibration control of rotating machinery p 551 N88-23229

Development of aeroelastic analysis methods for turborotors and propfans, including mistuning p 551 N88-23244

aeroelastic research Propfan model wind tunnel results p 501 N88-23246

Aeroelastic forced response analysis turbomachinery p 526 N88-23247 Modal forced response of propfans in yawed flow

p 551 N88-23253 Vibration and flutter analysis of the SR-7L large-scale

p 551 N88-23254 proptan p 552 N88-23255 Supersonic axial-flow fan flutter p 552 N88-23256 Stall flutter analysis of propfans

# Army Propulsion Lab., Cleveland, Ohio.

An overview of rotorcraft propulsion research at Lewis Research Center p 524 A88-40554

## B

# Boeing Military Airplane Development, Seattle, Wash.

Development and evaluation of an airplane fuel tank ullage composition model. Volume 2: Experimental determination of airplane fuel tank ullage compositions [AD-A190408] p 515 N88-22025

### Brown, Boveri und Cie, A.G., Mannheim (West Germany).

Evaluation of ceramic thermal barrier coatings for gas turbine engine components [ETN-88-91947] p 543 N88-22998

# C

# California Inst. of Tech., Pasadena.

Rotordynamic forces on centrifugal pump impellers p 543 A88-37108

Investigation of combustion in large vortices [AD-A190406] p 541 N88-22121

## Cambridge Acoustical Associates, Inc., Mass.

Structureborne noise measurements on a small twin-engine aircraft [NASA-CR-4137]

### Case Western Reserve Univ., Cleveland, Ohio.

Active control and system identification of rotordynamic structure p 551 N88-23230

# Complere, Inc., Hampton, Va.

Boundary-layer stability analysis of NLF and LFC experimental data at subsonic and transonic speeds p 483 A88-38925 [SAE PAPER 871859] Computing Devices Co., Ottawa (Ontario).

Development of a real-time aeroperformance analysis technique for the X-29A advanced technology demonstrator [AIAA PAPER 88-2145] p 512 A88-38738

### D

# Dayton Univ., Ohio.

An integral equation for the linearized supersonic flow over a wing [AD-A191408]

p 501 N88-22875 De Havilland Aircraft Co. of Canada Ltd., Downsview

(Ontario). A review of the de Havilland augmentor-wing powered-lift concept and its future applications

(SAE PAPER 872313) SAE PAPER 872313] p 507 A88-37184 Development of lift ejectors for STOVL combat aircraft

[SAE PAPER 872324] p 522 A88-37193 Department of National Defence, Ottawa (Ontario).

### The synthesis of ejector lift/vectored thrust for STOVL [SAE PAPER 872378] p 523 A88-37228

Deutsche Forschungs- und Versuchsanstalt fuer Luft-und Raumfahrt, Brunswick (West Germany).

A multilifting line method and its application in design and analysis of nonplanar wing configurations [DFVLR-FB-87-51] p 499 N88-22860

The transonic wind tunnel (TWB) at DFVLR, Brunswick (Federal Republic of Germany) [DFVLR-MITT-88-01] p 539 N88-22909

### Deutsche Forschungs- und Versuchsanstalt

Deutsche Forschungs- und Versuchsanstalt fuer Luftund Raumfahrt, Goettingen (West Germany).

Theoretical investigation of secondary instability of three-dimensional boundary-layer flows with application to the DFVLR-F5 model wing [DFVLR-FB-87-44]

p 547 N88-22330

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[DFVLR-MITT-87-18] p 502 N88-22876

Deutsche Lufthansa Aktiengesellschaft, Cologne (West Germany).

Activities report of Lufthansa

p 476 N88-22855 HSSN-0176-50861

Douglas Aircraft Co., Inc., Long Beach, Calif. An experimental investigation of flowfield about a

multielement airfoil p 481 A88-37937 [AIAA PAPER 88-2035] Oscillating airfoils: Achievements and conjectures p 496 N88-22008

IAD-A1904901 Draper (Charles Stark) Lab., Inc., Cambridge, Mass.

Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit

p 553 A88-38765 [AIAA PAPER 88-2172]

Duke Univ., Durham, N. C.

Reduced order models for nonlinear aerodynamics

p 501 N88-23248

Dynamic Engineering, Inc., Newport News, Va.

Computational validation of a parabolized Navier-Stokes solver on a sharp-nose cone at hypersonic speeds p 490 A88-40739 [AIAA PAPER 88-2566]

# E

Eidetics International, Inc., Torrance, Calif.

Flow visualization study of vortex manipulation on fighter configurations at high angles of attack p 549 N88-23130

Eloret Corp., Sunnyvale, Calif.
Flow visualization and pressure distributions for an p 487 A88-40601 all-body hypersonic aircraft

European Space Agency, Paris (France).

Digital processing of flight data of a helicopter without using anti-aliasing filters

p 517 N88-22890 [ESĂ-TT-1094] Servo-actuator control for sampled-data feedback

disturbance rejection p 529 N88-22903 [ESA-TT-1002] Comparison of different kinds of compact crossflow heat

p 550 N88-23169 [ESA-TT-1076] Standardized ice accretion thickness as a function of

cloud physics parameters p 553 N88-23346 [ESA-TT-1080]

# F

Florida Univ., Gainesville.

Numerical simulation of a subsonic jet in a crossflow p 478 A88-37209 [SAE PAPER 872343]

Flow Research, Inc., Kent, Wash.

Optimizing advanced presimultaneously updating flow advanced propeller designs variables and design parameters p 488 A88-40718 [AIAA PAPER 88-2532]

Unsteady aerodynamics of a Wortmann FX-63-137 wing in a fluctuating wind field

p 496 N88-22006 [AD-A190128]

Fokker B.V., Amsterdam (Netherlands).

Activities report in aerospace p 476 N88-22856 [FTN-88-91566]

# G

General Dynamics Corp., Fort Worth, Tex.

Parametric study of supersonic STOVL flight characteristics p 518 N88-22893 [NASA-CR-177330]

General Electric Co., Cincinnati, Ohio.

Scale model acoustic testing of counterrotating fans p 523 A88-37947 [AIAA PAPER 88-2057]

George Washington Univ., Hampton, Va. Unexpected/expected results from the Langley 20-Inch Supersonic Wind Tunnel during initial checkout p 531 A88-37911 [AIAA PAPER 88-1999]

Georgia Inst. of Tech., Atlanta.

Application of Navier-Stokes analysis to stall flutter p 530 N88-23249

Grumman Aerospace Corp., Bethpage, N.Y. Impact of bypass ratio on thrust-to-weight for V/STOL p 523 A88-37237 [SAE PAPER 872348]

On the prediction of highly vortical flows using an Euler equation model, part 2 p 547 N88-22305 IAD-A1902451

# Н

Hamburg Model Basin (West Germany).

Measurements of the time dependent velocity field surrounding a model propeller in uniform water flow p 550 N88-23155

Harvey Mudd Coll., Claremont, Calif.

Development of a block Lanczos algorithm for free vibration analysis of spinning structures

p 545 A88-40117

Hughes Aircraft Co., El Segundo, Calif.

Advanced capacitor development p 546 N88-22276 IAD-A1899851

Illinois Univ., Urbana.

Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct p 547 N88-22320 1AD-A1907721

IMI Summerfield, Kidderminster (England).

Water flow visualisation of a ramrocket combustion p 549 N88-23138 chamber

Imperial Coll. of Science and Technology, London (England).

Flow in out-of-plane double S-bends

p 484 A88-39011

Institut Franco-Allemand de Recherches, St. Louis (France).

Acoustic propagation in the low atmosphere. Experimental study and modeling by the radius method p 556 N88-22713 [ISL-CO-247/86]

Instituto Nacional de Tecnica Aeroespacial, Esteban Terradas, Torrejon de Ardoz (Spain).

A panel method based on velocity potential to compute harmonically oscillating lift surface systems p 546 N88-22290 [ETN-88-91886]

JAI Associates, Mountain View, Calif.

Tip vortices of isolated wings and helicopter rotor blades

p 501 N88-22874 [AD-A191336]

Joint Publications Research Service, Arlington, Va. Investigation of side-wall effects in wind tunnel with p 498 N88-22241 supercritical airfoil testing

Theoretical model and numerical solution for compressible viscous vortex cores p 498 N88-22243 Mixed direct-inverse problem of transonic cascade

p 498 N88-22244 Influence of unsteady aerodynamic forces on dynamic N88-22245 response of variable sweep aircraft p 516 Model study of thermal stresses in gas-turbine blades p 542 N88-22989 with protective coating Dependence of structure of stabilized ZrO2 coatings on p 543 N88-22990 condensation rate

Aircraft flight dynamics research in past decade reviewed

Kansas Univ. Center for Research, Inc., Lawrence.

Analysis of a range estimator which uses MLS angle measurements p 507 N88-22884

[NASA-CR-182896] Kentron International, Inc., Hampton, Va.

Supersonic jet plume interaction with a flat plate [SAE PAPER 872361] p 479 A88-

p 479 A88-37222 Kings Coll., London (England).

Flow in out-of-plane double S-bends

p 484 A88-39011

Leicester Univ. (England).

Measurements of aerodynamic forces on unsteadily moving bluff parachute canopies p 549 N88-23137 Lockheed-California Co., Burbank.

KRASH parametric sensitivity study: Transport category airplanes

[AD-A189962] Lockheed-Georgia Co., Marietta.

Analytical sensor redundancy asse

p 521 N88-22901 [NASA-CR-182892]

p 515 N88-22024

Lockheed Missiles and Space Co., Sunnyvale, Calif.

Heating requirements and nonadiabatic surface effects for a model in the NTF cryogenic wind tunnel

AIAA PAPER 88-2044] p 534 A88-37944 Fluid mechanics of dynamic stall. I - Unsteady flow [AIAA PAPER 88-2044] oncepts p 485 A88-39511
Fluid mechanics of dynamic stall. II - Prediction of full p 485 A88-39512 scale characteristics

М

MARC Analysis Research Corp., Pato Alto, Calif. MHOST: An efficient finite element program for inelastic

p 525 N88-22394 analysis of solids and structures Martin Marietta Corp., Denver, Colo.

Digital avionics design and reliability analyzer

[NASA-CR-181641] p 554 N88-23472

Massachusetts Inst. of Tech., Cambridge. Describing the source created by turbulent flow over

orifices and louvers p 556 N88-22706 [AD-A190254] Analysis and design of gain scheduled control

systems NASA-CR-1828671 p 529 N88-22904

McDonnell Aircraft Co., St. Louis, Mo. STOVL acoustic fatigue technologies

[SAE PAPER 872360] p 555 A88-37221 Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 1: Wind tunnel

test pressure data report [NASA-CR-177343-VOL-1] Propulsion and airframe aerodynamic interactions of

supersonic V/STOL configurations. Volume 2: Wind tunnel test force and moment data report p 500 N88-22867 [NASA-CR-177343-VOL-2]

Propulsion and airframe aerodynamic interactions of supersonic V/STOL configurations. Volume 4: Summary [NASA-CR-177343-VOL-4] p 500 N88-22868 Nondestructive evaluation of large scale composite components

p 542 N88-22954 AD-A1909981

McDonnell-Douglas Research Labs., St. Louis, Mo. Unsteady features of jets in lift and cruise modes for VTOL aircraft

p 478 A88-37220 [SAE PAPER 872359] Experimental investigation of Hover flowfields in water at the McDonnell Douglas Research Laboratories

p 549 N88-23135

Michigan Univ., Ann Arbor. The structure of sonic underexpanded turbulent air jets in still air [AD-A190856] p 500 N88-22870

Mississippi State Univ., Mississippi State.

Three-dimensional unsteady transonic viscous-inviscid

interaction using the Euler and boundary-layer equations
[AIAA PAPER 88-2578] p 491 A88-40747 [AIAA PAPER 88-2578]

# N

Nagoya Univ. (Japan).

Analysis for high compressible supersonic flow in converging nozzle p 500 N88-22869

National Aeronautical Establishment, Ottawa (Ontario). The application of linear maximum likelihood estimation of aerodynamic derivatives for the Bell-205 and Bell-206 p 518 N88-22894 [AD-A191279]

National Aeronautics and Space Administration,

Washington, D.C. Overview of the US/UK ASTOVL program
[SAE PAPER 872365] p 473

p 473 A88-37238 Rotorcraft research at NASA p 475 A88-40552 The NASA/AHS Rotorcraft Noise Reduction Program p 475 A88-40553

National Aero-Space Plane p 540 A88-41288 [AAS PAPER 87-127] Designs of profiles for cascades

p 547 N88-22326 NASA-TT-201611 Method and device for the detection and identification

of a helicopter p 556 N88-22698 [NASA-TT-20251]

Flow quality of NAL two-dimensional transonic wind tunnel. Part 1: Mach number distributions, flow angularities and preliminary study of side wall boundary layer suction p 539 N88-22911 [NASA-TT-20209]

National Aeronautics and Space Administration. Ames Research Center, Moffett Field, Calif.

Propulsion-induced effects caused by out-of-ground effects [SAE PAPER 872307] p 477 A88-37179

Quiet Short-Haul Research Aircraft - A summary of flight research since 1981

p 483 A88-38950

p 555 A88-39722

p 537 A88-40722

p 490 A88-40739

p 491 A88-40745

p 493 A88-40757

p 493 A88-40762

p 494 A88-40764

p 494 A88-40766

flow around a

p 494 A88-40767

p 497 N88-22012

p 497 N88-22015

Flight evaluation of an integrated control and display system for high-precision manual landing flare of powered-lift STOL aircraft p 508 A88-37187 [SAE PAPER 872316] Aerodynamic flow quality and acoustic characteristics of the 40- by 80-foot test section circuit of the National Full-Scale Aerodynamic Complex ISAE PAPER 8723281 p 530 A88-37197 integrated control and display research for transition and vertical flight on the NASA V/STOL Research Aircraft (VSRA) [SAE PAPER 872329] p 526 A88-37198 Numerical investigation of a jet in ground effect with a [SAE PAPER 872344] p 478 A88-37210 The RSRA/X-Wing experiment - A status report ISAE PAPER 872371) p 479 A88-37225 Civil applications of high speed rotorcraft and powered lift aircraft configurations [SAE PAPER 872372] p 501 A88-37226 Using frequency-domain methods to identify XV-15 aeroelastic modes [SAE PAPER 872385] p 510 A88-37234 Wave drag and high-speed performance of supersonic STOVL fighter configurations (SAE PAPER 872311) p 479 A88-37235 Application of empirical and linear methods to VSTOL powered-lift aerodynamics SAE PAPER 8723411 p 479 A88-37236 Impact of bypass ratio on thrust-to-weight for V/STOL p 523 A88-37237 [SAE PAPER 872348] Calculation of external-internal flow fields for mixed-compression inlets p 479 A88-37353 Helicopter terminal approach using differential GPS with vertical-axis enhancement p 503 A88-37397 Numerical study of the skin friction on a spheroid at p 482 A88-38376 incidence Visualization and wake surveys of vortical flow over a delta wing p 482 A88-38377 Flight testing a V/STOL aircraft to identify a full-envelope aerodynamic model IAIAA PAPER 88-21341 p 512 A88-38731 Properties of a half-delta wing vortex p 483 A88-38985 Flow visualization and pressure distributions for an all-body hypersonic aircraft p 487 A88-40601 Direct assessment of two-dimensional wind-tunnel interference from measurements on two interfaces [AIAA PAPER 88-2539] p 537 A88-40723 An upwind differencing scheme for the time-accurate incompressible Navier-Stokes equations [AIAA PAPER 88-2583] p 492 A88-40752 An overview of hypersonic aerothermodynamics p 495 A88-41270 Computational fluid dynamics drag prediction: Results from the Viscous Transonic Airfoil Workshop [NASA-TM-100095] p 496 N88-22009 [NASA-TM-100095] Navier-Stokes Transonic computations strake-generated vortex interactions for a fighter-like INASA-TM-1000091 p 497 N88-22010 Boundary-layer and wake measurements on a swept. circulation-control wing [NASA-TM-89426] p 497 N88-22013 Bifurcations in unsteady aerodynamics-implications for testina [NASA-TM-100083] p 497 N88-22014 Real-time flight test data distribution and display (NASA-TM-1004241 p 538 N88-22050 On the validation of a code and a turbulence model appropriate to circulation control airfoils [NASA-TM-100090] p 499 N88-22864 An investigation of the ability to recover from transients following failures for single-pilot rotorcraft [NASA-TM-100078] p 529 N88-22905 Water facilities in retrospect and prospect: An illuminating tool for vehicle design p 539 N88-23126 Vortex breakdown and control experiments in the Ames-Dryden water tunnel p 549 N88-23127 National Aeronautics and Space Administration. Flight Research Center, Edwards, Calif. Aircraft flight flutter testing at the NASA Ames-Dryden Flight Research Facility [AIAA PAPER 88-2075] p 510 A88-38702 Formulaton of a general technique for predicting pneumatic attenuation errors in airborne pressure sensing [AIAA PAPER 88-2085] p 518 A88-38707 The NASA Integrated Test Facility and its impact on flight research [AIAA PAPER 88-2095] p 535 A88-38711 Development of an integrated set of research facilities for the support of research flight test

[AIAA PAPER 88-2096]

Effects of maneuver dynamics on drag polars of the Theoretical investigations, and correlative studies for X-29A forward-swept-wing aircraft with automatic wing NLF, HLFC, and LFC swept wings at subsonic, transonic camber control and supersonic speeds I AIAA PAPER 88-2144 I p 527 A88-38737 (SAE PAPER 871861) Development of a real-time aeroperformance analysis Mechanisms of active control for noise inside a vibrating technique for the X-29A advanced technology cylinder demonstrator A transonic wind tunnel wall interference prediction [AIAA PAPER 88-2145] p 512 A88-38738 code Development of an interactive real-time graphics system [AIAA PAPER 88-2538] for the display of vehicle space positioning Computational validation of a parabolized Navier-Stokes [AIAA PAPER 88-2167] p 536 A88-38744 solver on a sharp-nose cone at hypersonic speeds The PC/AT compatible computer as a mission control [AIAA PAPER 88-2566] center display processor at Ames-Dryden Flight Research Experimental measurements on an oscillating 70-degree Facility delta wing in subsonic flow [AIAA PAPER 88-2168] p 536 A88-38745 [AIAA PAPER 88-2576] Performance improvements of an F-15 airplane with an Unsteady viscous-inviscid interaction procedures for integrated engine-flight control system p 527 A88-38747 transonic airfoils using Cartesian grids [AIAA PAPER 88-2591] [AIAA PAPER 88-2175] Development of a mobile research flight test support Calculations of three-dimensional flows using the capability [AIAA PAPER 88-2087] isenthalpic Euler equations with implicit flux-vector Techniques used in the F-14 variable-sweep transition splitting flight experiment [AIAA PAPER 88-2516] (AIAA PAPER 88-2110) p 513 A88-38762 Riblet drag reduction at flight conditions Flight tests of external modifications used to reduce blunt [AIAA PAPER 88-2554] Experimental and theoretical study of the effects of wing [AIAA PAPER 88-2553] p 494 A88-40763 geometry on a supersonic multibody configuration
[AIAA PAPER 88-2510] p 494 A88 National Aeronautics and Space Administration. Hugh L. Dryden Flight Research Center, Edwards, Calif. Navier-Stokes computation of Effects of update and refresh rates on flight simulation round-edged double-delta wing visual displays [AIAA PAPER 88-2560] [NASA-TM-100415] p 516 N88-22033 Laser velocimeter measurements in a wing-fuselage type Development of a mobile research flight test support juncture capability [NASA-TM-100588] [NASA-TM-100428] p 506 N88-22883 Inflow measurement made with a laser velocimeter on National Aeronautics and Space Administration. Hugh L. Dryden Flight Research Facility, Edwards, Calif. a helicopter model in forward flight. Volume 3: Rectangular planform blades at an advance ratio of 0.30 Development of a block Lanczos algorithm for free [NASA-TM-100543] vibration analysis of spinning structures p 545 A88-40117 National Aeronautics and Space Administration. Langley Research Center, Hampton, Va. Supersonic jet plume interaction with a flat plate [SAE PAPER 872361] p 479 A88-37222 The Basic Aerodynamics Research Tunnel - A facility dedicated to code validation [AIAA PAPER 88-1997]

[AIAA PAPER 88-2008]

[AIAA PAPER 88-2010]

[AIAA PAPER 88-2013]

[AIAA PAPER 88-2024]

[AIAA PAPER 88-2029]

[AIAA PAPER 88-2033]

[AIAA PAPER 88-2035]

[AIAA PAPER 88-2036]

[AIAA PAPER 88-2044]

[AIAA PAPER 88-2048]

[AIAA PAPER 88-2172]

[SAE PAPER 871757]

(SAE PAPER 871859)

p 535 A88-38712

propulsion wind tunnel models

high-angle-of-attack behavior of airplanes

flow field in a transonic wind tunnel

Suspension and Balance Systems

using a three component laser velocimeter

along a longitudinally slotted wind-tunnel wall

system of the National Transonic Facility

Drag measurements on a body of revolution in Langley's

A forecast of new test capabilities using Magnetic

Measurement of leading edge vortices from a delta wing

Velocity profile similarity for viscous flow development

A study of aeroelastic stability for the model support

An experimental investigation of flowfield about a

Highlights of experience with a flexible walled test

section in the NASA Langley 0.3-meter transonic cryogenic

Heating requirements and nonadiabatic surface effects for a model in the NTF cryogenic wind tunnel

A flow-transfer device with nonmetallic diaphragms for

Use of dynamically scaled models for studies of the

Flight test results of a vector-based failure detection

Theoretical and experimental analysis of the slotted-wall

Boundary-layer stability analysis of NLF and LFC

experimental data at subsonic and transonic speeds

and isolation algorithm for a redundant strapdown inertial

p 532 A88-37918

p 532 A88-37921

p 544 A88-37929

p 481 A88-37932

p 533 A88-37936

p 481 A88-37937

p 533 A88-37938

p 534 A88-37944

p 534 A88-37945

p 535 A88-38692

p 553 A88-38765

p 482 A88-38775

p 483 A88-38925

13-inch Magnetic Suspension and Balance System

Procedures and requirements for testing in the Langley Research Center unitary plan wind tunnel p 497 N88-22016 [NASA-TM-100529] Shape sensitivity analysis of wing static aeroelastic characteristics

[NASA-TP-2808] p 516 N88-22031 Modifications to the Langley 8-foot transonic pressure p 531 A88-37910 tunnel for the laminar flow control experiment

Unexpected/expected results from the Langley 20-Inch [NASA-TM-40321 p 538 N88-22047 Supersonic Wind Tunnel during initial checkout Aerothermal tests of quilted dome models on a flat plate at a Mach number of 6.5 I AIAA PAPER 88-19991 p 531 A88-37911 A review of Magnetic Suspension and Balance

[NASA-TP-2804] p 547 N88-22325 Improvements to tilt rotor performance through passive blade twist control [NASA-TM-100583] p 548 N88-22434

directivity Advancing-side and retreating-side interactions of model rotor blade-vortex interaction noise [NASA-TP-2784] p 556 N88-22710 Langley aerospace test highlights, 1987

[NASA-TM-100595] p 558 N88-22853 Inflow measurements made with a laser velocimeter on a helicopter model in forward flight. Volume 4: Tapered

planform blades at an advance ratio of 0.15 [NASA-TM-1005441 p 499 N88-22863

Minimum weight design of rotorcraft blades with multiple frequency and stress constraints [NASA-TM-100569] p 517 N88-22892

Towards a damage tolerance philosophy for composite materials and structures [NASA-TM-100548] p 542 N88-22949

A description of an automated database comparison program [NASA-TM-100609] p 554 N88-23463

Accuracy versus convergence rates for a three dimensional multistage Euler code p 554 N88-23519

Advanced turboprop aircraft flyover noise: Annoyance to counter-rotating-propeller configurations with an equal number of blades on each rotor, preliminary results

[NASA-TM-100612] p 557 N88-23547 National Aeronautics and Space Administration. Lewis N88-23547 Research Center, Cleveland, Ohio.

Flight propulsion control integration for V/STOL aircraft

[SAE PAPER 872330] p 522 A88-37199 NASA supersonic STOVL propulsion technology program

[SAE PAPER 872352] p 523 A88-37215 Test stand performance of a convertible engine for advanced V/STOL and rotorcraft propulsion

[SAE PAPER 872355] p 523 A88-37217 Turbofan engine core noise source diagnostics

p 524 A88-39707 Combustion noise from gas turbine aircraft engines measurement of far-field levels p 555 A88-39708 An overview of rotorcraft propulsion research at Lewis p 524 A88-40554

# National Aerospace Lab., Amsterdam (Netherlands).

Porous wind tunnel corrections for counterrotation propeller testina p 498 N88-22019 INASA-TM-1008731 Small engine components test facility turbine testing p 525 N88-22037 [NASA-TM-100887] Lewis Structures Technology, 1988. Volume 2: Structural Mechanics p 548 N88-22382 [NASA-CP-3003-VOL-2] High-temperature combustor liner tests in structural p 525 N88-22383 component response test facility Life assessment of combustor liner using unified p 525 N88-22384 constitutive models The composite blade structural analyzer (COBSTRAN) p 525 N88-22390 Computational structural mechanics for engine p 525 N88-22399 structures p 548 N88-22418 Mode 2 fracture mechanics p 548 N88-22430 Research sensors Review and assessment of the HOST turbine heat p 526 N88-22431 transfer program Structural dynamics branch research and accomplishments for fiscal year 1987 D 549 N88-22446 INASA-TM-1002791 Research and technology p 558 N88-22851 INASA-TM-1001721 NASA advanced turboprop research and concept validation program p 526 N88-22902 [NASA-TM-100891] Computerized life and reliability modelling for turboprop transmissions p 551 N88-23220 [NASA-TM-100918] Lewis Structures Technology, 1988. Volume 1: Structural p 551 N88-23226 [NASA-CP-3003-VOL-1] National Aerospace Lab., Amsterdam (Netherlands). Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation p 498 N88-22017 [NLR-MP-86074-U] Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model p 528 N88-22038 IPB88-1498851 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure p 547 N88-22369 INLR-MP-86059-U1 Development of a flexible and economic helicopter engine monitoring system p 517 N88-22887 [PB88-165147] National Aerospace Lab., Tokyo (Japan). Navier Stokes computation of the flow field over delta wings with spanwise leading edge blowing p 489 A88-40734 [AIAA PAPER 88-2558] Design method for laminar flow control of two-dimensional airfoils in incompressible flow. Numerical study of LFC design concepts [DE88-751809] D 498 N88-22859 First flight simulator test of the head-up display for NAL QSTOL experimental aircraft (ASUKA) p 521 N88-22896 [DE88-751804] Basic design of a flight director system for NAL STOL research aircraft p 521 N88-22897 [DE88-751806] National Bureau of Standards, Boulder, Colo. EMR (Electromagnetic Radiation) test evaluation of reverberating chamber located at RADC (Rome Air Development Center), Griffiss AFB (Air Force Base), Rome, New York p 538 N88-22048 [PB88-178827] National Research Council of Canada, Ottawa (Ontario). The use of the NRC/NAE water facilities in Canadian aeronautical research and development p 539 N88-23132 National Telecommunications and Information Administration, Boulder, Colo. Investigations of test methodology for the stress loading p 538 N88-22049 [PB88-166095] National Transportation Safety Board, Washington, D. C. Aircraft accident reports, brief format, US civil and foreign viation, issue number 10 of 1986 accidents p 502 N88-22020 [PB87-916912] Aircraft accident report: North Star Aviation, Inc., PA-32 RT-300, N39614 and Alameda Aero Club Cessna 172, N75584, Oakland, California, March 31, 1987 p 502 N88-22021 [PB87-910412] Aircraft accident report: Midair collision of US Army U-21A, Army 18061 and Sachs Electric Company Pipel PA-31-350, N60SE, Independence, Missouri, January 20, 1987 p 502 N88-22877 [PB88-910401]

Aircraft accident/incident summary reports: Modena, Pennsylvania, March 17, 1986; Redwater, Texas, April 4, [PB88-910403] p 502 N88-22878 Naval Air Development Center, Warminster, Pa. Development of a high-temperature resistant (700 F), corrosion-preventive organic coating p 543 N88-23009 [AD-A191407] Naval Postgraduate School, Monterey, Calif. High Reynolds number, low Mach number, steady flow field calculations over a NACA 0012 airfoil using Navier-Stokes and interactive boundary layer theory p 496 N88-22005 [AD-A189871] The effects of torque response and time delay on rotorcraft vertical axis handling qualities p 515 N88-22023 [AD-A189873] Heat transfer modeling of jet vane Thrust Vector Control (TVC) systems p 524 N88-22034 IAD-A1901061 North Carolina State Univ., Raleigh. Unsteady viscous-inviscid interaction procedures for transonic airfoils using Cartesian grids [AIAA PAPER 88-2591] p 493 A88-40757 Notre Dame Univ., Ind. Visualization techniques for studying high angle of attack separated vortical flows [AIAA PAPER 88-2025] p 544 A88-37930 Visualization and wake surveys of vortical flow over a p 482 A88-38377 delta wing Leading edge vortex dynamics on a pitching delta [AIAA PAPER 88-2559] p 489 A88-40735 O Oak Ridge National Lab., Tenn. Investigation of aeroacoustic mechanisms by remote thermal imaging [DE88-002612] p 538 N88-22046 Office National d'Etudes et de Recherches

Aerospatiales, Paris (France). The ONERA water tunnels test possibilities for flow visualization in aeronautical and Naval domains p 550 N88-23139 La Recherche Aerospatiale, bimonthly bulletin, number 1987-3, 238/May-June

p 550 N88-23161 [ESA-TT-1075] Ohio State Univ., Columbus. Experimental measurements on an oscillating 70-degree

delta wing in subsonic flow p 491 A88-40745 I AIAA PAPER 88-25761 Old Dominion Univ., Norfolk, Va.

Flow solution on a dual-block grid around an airplane p 479 A88-37355 An experimental investigation of the aerodynamic characteristics of slanted base ogive cylinders using magnetic suspension technology

p 481 A88-37919 [AIAA PAPER 88-2011] Progress towards extreme attitude testing with Magnetic Suspension and Balance Systems

p 532 A88-37920 [AIAA PAPER 88-2012] Aerodynamic investigation by infrared imaging

[AIAA PAPER 88-2523] Calculations of three-dimensional flows using the isenthalpic Euler equations with implicit flux-vector splitting [AIAA PAPER 88-2516] p 493 A88-40762

Nonlinear wave interactions in swept wing flows
NASA-CR-41421 p 550 N88-23160 [NASA-CR-4142]

PEDA Corp., Palo Alto, Calif.

CSCM Navier-Stokes thermal/aerodynamic analysis of hypersonic nozzle flows with slot injection and wall

n 493 A88-40756 [AIAA PAPER 88-2587] Pratt and Whitney Aircraft, East Hartford, Conn.

Life prediction modeling based on cyclic damage p 548 N88-22426 accumulation Fatigue damage modeling for coated single crystal p 542 N88-22427 superallovs PRC Kentron, Inc., Hampton, Va.

Flight test results of a vector-based failure detection and isolation algorithm for a redundant strapdown inertial measurement unit p 553 A88-38765

[AIAA PAPER 88-2172] Princeton Univ., N. J.

Detection of large-scale organized motions in a turbulent p 484 A88-39023 boundary layer

Purdue Univ., West Lafayette, Ind.

Research as part of the Air Force in aero propulsion technology (AFRAPT) program p 525 N88-22036 IAD-A1903361

The 2-D and 3-D time marching transonic potential flow p 501 N88-23245 method for propfans

Rensselaer Polytechnic Inst., Troy, N.Y.

Problems in nonlinear continuum dynamics p 554 N88-22691 [AD-A190538] Royal Aircraft Establishment, Farnborough (England). Overview of the US/UK ASTOVL program p 473 A88-37238 ISAF PAPER 8723651

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Saab-Scania, Linkoping (Sweden).

Investigation on the movement of vortex burst position with dynamically changing angle of attack for a schematic deltawing in a watertunnel with correlation to similar studies in windtunnel p 550 N88-23152 Sandia National Labs., Albuquerque, N. Mex.

Heating requirements and nonadiabatic surface effects for a model in the NTF cryogenic wind tunnel p 534 A88-37944 [AIAA PAPER 88-2044] Ultrasonic Time-Of-Flight Diffraction (TOFD) measurements of crack depths in an acceleration reservoir

of a high velocity research gun p 538 N88-22907 [DE88-006644]

Sikorsky Aircraft, Stratford, Conn.

Acoustic characteristics of 1/20-scale model helicopter p 557 N88-23548 [NASA-CR-177355]

Societe Bertin et Cie, Plaisir (France).

Qualification of a water tunnel for force measurements p 539 N88-23128 on aeronautical models

Southampton Univ. (England). Adaptive wall research with two- and three-dimensional

models in low speed and transonic tunnels p 533 A88-37939 [AIAA PAPER 88-2037] Flexiwall 3 SO: A second order predictive strategy for

rapid wall adjustment in two-dimensional compressible p 498 N88-22018 [NASA-CR-181662]

Aerofoil testing in a self-streamlining flexible walled wind tunnel

[NASA-CR-4128]

p 499 N88-22865

Stanford Univ., Calif. Properties of a half-delta wing vortex

p 483 A88-38985 Navier Stokes computation of the flow field over delta wings with spanwise leading edge blowing

p 489 A88-40734 [AIĀA PAPER 88-2558] Contraction design for small low-speed wind tunnels p 537 N88-22045 [NASA-CR-182747]

Turbulent reacting flows and supersonic combustion p 541 N88-22115 [AD-A189690]

Experimental studies of vortex flows p 551 N88-23171 [NASA-CR-182874]

Sterling Software, Palo Alto, Calif.

An upwind differencing scheme for the time-accurate

incompressible Navier-Stokes equations p 492 A88-40752 [AIAA PAPER 88-2583]

Strathclyde Univ., Glasgow (Scotland). The use of rule induction to assist in the diagnosis of avionic circuit board defects

p 521 N88-22899 [ETN-88-92077] Sun Refining and Marketing Co., Marcus Hooks, Pa. Turbine fuels from tar sands bitumen and heavy oil. Volume 2, phase 3: Process design specifications for a

turbine fuel refinery charging San Ardo heavy crude oil p 543 N88-23011 [AD-A1901201 Sverdrup Technology, Inc., Cleveland, Ohio. Specialty three-dimensional finite element analysis p 548 N88-22393

Structural analyses of engine wall cooling concepts and laterials p 542 N88-22405 materials

Syracuse Univ., N. Y.

An isentropic compression heated Ludwieg tube transient wind tunnel p 533 A88-37926 [AIAA PAPER 88-2019]

Technion - Israel Inst. of Tech., Haifa.

Numerical study of the skin friction on a spheroid at cidence p 482 A88-38376 Visualisation of the flow at the tip of a high speed axial flow turbine rotor

p 546 N88-22300 [AD-A189928] Technische Hochschule, Aachen (West Germany).

Short duration flow establishment on a profile in a /ater-Ludwieg-Tunnel p 549 N88-23134 Water-Ludwieg-Tunnel

Technische Hogeschool, Delft (Netherlands).

Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence

[LR-518] p 499 N88-22861 Design studies of primary aircraft structures in ARALL

(LR-520) p 517 N88-22888 The initial calculation of range and mission fuel during

conceptual design ILR-5251 p 517 N88-22889

Texas A&M Univ., College Station.

Experimental investigation of non-planar sheared outboard wing planforms [AIAA PAPER 88-2549]

p 489 A88-40731 Toledo Univ., Ohio.

A computational procedure for automated flutter

Tracor Hydronautics, Inc., Laurel, Md.

An experimental child

An experimental study to determine the flow and the subsonic static and dynamic stability characteristics of aircraft operating at high angles-of-attack

p 518 N88-23129 Transportation Systems Center, Cambridge, Mass.

General aviation activity and avionics survey: 1986 data

[AD-A189986]

Universal Energy Systems, Inc., Dayton, Ohio.

Soft-ground aircraft arresting systems

[AD-A190838] p 539 N88-22912

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[NASA-CR-182759]

p 497 N88-22011

p 476 N88-22003

Van der Velden (Alexander J. M.), Berkeley, Calif.

Conceptual final paper on the preliminary design of an oblique flying wing SST [NASA-CR-182879] p 517 N88-22891

VDO-Luttfahrtgeraete Werk Adolf Schindling G.m.b.H.,
Frankfurt (West Germany).

Basic design studies for the realization of liquid crystal

display systems in aircraft [VA-87-001] p 521 N88-22900

Vigyan Research Associates, Inc., Hampton, Va.

An analytical method for the ditching analysis of an airborne vehicle

[AIAA PAPER 88-2521] p 514 A88-40711

A panel method procedure for interference assessment in slotted-wall wind tunnels [AIAA PAPER 88-2537] p 537 A88-40721

Experimental investigation of non-planar sheared outboard wing planforms

[AIAA PAPER 88-2549] p 489 A88-40731

Navier-Stokes computation of flow around a round-edged double-delta wing

[AIAA PAPER 88-2560] p 494 A88-40767 Virginia Polytechnic Inst. and State Univ., Blacksburg. Mechanisms of active control for noise inside a vibrating p 555 A88-39722

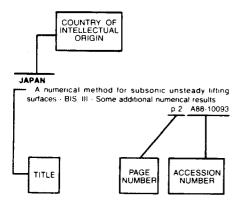
Active control of sound fields in elastic cylinders by brational inputs p 556 A88-39725 vibrational inputs A numerical model of unsteady, subsonic aeroelastic

behavior [NASA-TM-101126] p 499 N88-22862

C-5

# FORE-ĠN

# Typical Foreign Technology Index Listing



Listings in this index are arranged alphabetically by country of intellectual origin. The title of the document is used to provide a brief description of the subject matter. The page number and the accession number are included in each entry to assist the user in locating the citation in the abstract section. If applicable, a report number is also included as an aid in identifying the document.

# **AUSTRALIA**

A role for fibre optics in antenna measurements p 544 A88-38116

Effect of load duration on the fatigue behaviour of graphite/epoxy laminates containing delaminations

p 541 A88-40174

# C

A review of the de Havilland augmentor-wing powered-lift

concept and its future applications

[SAE PAPER 872313] p 507 A88-37184 Development of lift ejectors for STOVL combat aircraft [SAE PAPER 872324] p 522 A88-37193

The synthesis of elector lift/vectored thrust for STOVL [SAE PAPER 872378] p 523 A88-37228

The Canadian Marconi Company GPS receiver - Its p 503 A88-37394 development, test, and future

Optimum porosity for an inclined-hole transonic test section wall treated for edgetone noise reduction

[AIAA PAPER 88-2003] AIAA PAPER 88-2003] p 531 A88-37914 The application of linear maximum likelihood estimation of aerodynamic derivatives for the Bell-205 and Bell-206

p 518 N88-22894 The use of the NRC/NAE water facilities in Canadian aeronautical research and development

### p 539 N88-23132 CHINA, PEOPLE'S REPUBLIC OF

The research on adaptive wall wind tunnel in Northwestern Polytechnical University of China

[AIAA PAPER 88-2040] p 534 A88-37942 Application of efficient iteration scheme AF2 to computations of transonic full-potential flows wing-body combinations p 481 A88-38177

Numerical calculations of a class of optimal flight trajectories p 553 A88-38178

The modelling technique of the flight system in flight simulator p 553 A88-38179 Some aspects of the reliability analysis of aircraft p 544 A88-38181 structures

Experimental investigation on rigid hollow hemispherical parachute model in accelerating and steady flow

p 482 A88-38185 Linear dynamics of supersonic inlet

p 482 A88-38186 Behaviour of damage tolerance of composite aircraft ructures p 544 A88-38187

The characteristics of asymmetric vortices and side forces on a sharp-nosed body with wing and vertical tail p 482 A88-38188

A study of digital fly-by-wire control system design for elastic aircraft p 527 A88-38191

Control law design of a CCV airplane p 527 A88-38192

Analysis of limit cycle flutter of an airfoil in incompressible p 546 A88-41219 Investigation of side-wall effects in wind tunnel with supercritical airfoil testing p 498 N88-22241

Theoretical model and numerical solution for compressible viscous vortex cores p 498 N88-22243 Mixed direct-inverse problem of transonic cascade

p 498 N88-22244 Influence of unsteady aerodynamic forces on dynamic response of variable sweep aircraft p 516 N88-22245 flight dynamics research in past decade reviewed p 518 N88-23031

### **EGYPT**

Fourth-order accurate calculations of compressible boundary layers on aerospace [AIAA PAPER 88-2522] p 487 A88-40712

### FRANCE

Two-dimensional and three-dimensional adaptation at the T2 transonic wind tunnel of Onera/Cert

[AIAA PAPER 88-2038] p 534 Calculation of transonic rotor noise using a frequency domain formulation p 555 A88-38380

Development of a variational method for chemical kinetic sensitivity analysis p 541 A88-38490 Navigation by satellite - The next step for civil aviation

p 506 A88-39375 Experimental study of a supersonic turbulent boundary layer using a laser Doppler anemometer

p 485 A88-39623

Reflections on the integration of avionics equipment p 519 A88-40517

Implementation of aeronautical mobile satellite services p 506 A88-40519

Aerospace equipment - Evolution and future problems p 474 A88-40522

Aerospace progress and research anniversary of ONERA ch - The fortieth p 557 A88-40548 Experimental and numerical study of the propeller/fixed

[AIAA PAPER 88-2571]

On the use of subcycling for solving the compressible Navier-Stokes equations by operator-splitting and finite element methods p 495 A88-41269

Acoustic propagation atmosphere low Experimental study and modeling by the radius method [ISL-CO-247/86] p 556 N88-22713

Qualification of a water tunnel for force measurements on aeronautical models p 539 N88-23128 The ONERA water tunnels test possibilities for flow

visualization in aeronautical and Naval domains p 550 N88-23139 La Recherche Aerospatiale, bimonthly builetin, number 1987-3, 238/May-June

p 550 N88-23161

[ESA-TT-1075]

G

### **GERMANY DEMOCRATIC REPUBLIC**

The effect of aircraft angular vibrations on the quality of remotely sensed images p 520 A88-41096 Avionics for transport aircraft - Current development status p 520 A88-41098

### **GERMANY, FEDERAL REPUBLIC OF**

Cascade lift ratios for radial and semiaxial rotating p 543 A88-37110 New structural technologies for the Dornier 328

fuselage p 473 A88-37297 Large-scale model for experimental wind tunnel p 531 A88-37298 investigations

Adaptation of flexible wind tunnel walls for supersonic [AIAA PAPER 88-2039] p 534 A88-37941

The use of 2-D adaptive wall test sections for 3-D

flows [AIAA PAPER 88-2041] p 534 A88-37943

Corrosion-resistant thermal barrier coatings p 540 A88-38315

METEOPOD, an airborne system for measurements of mean wind, turbulence, and other meteorological parameters

[AIAA PAPER 88-2103] p 519 A88-38715

Program review of European Fighter Aircraft [AIAA PAPER 88-2120] p 511 A88-38721

An airborne realtime data processing and monitoring system for research aircraft

[AIAA PAPER 88-2165] p 506 A88-38743 Piezo-electric foils as a means of sensing unsteady surface forces on flow-around bodies

p 483 A88-38976 Computational study of the unsteady flow due to wakes passing through a channel p 483 A88-38984 Dornier 328 taking shape p 514 A88-39415 CFRP landing flaps for the Airbus A320

p 474 A88-39416 Modern surface protections for aircraft

A88-39417 p 541 Technologies for hypersonic flight

p 540

A88-39419

Computer vision for flight vehicles

p 527 A88-39485 Computation of cascade flow using a finite-flux-element method

p 485 A88-39488 Taxiway safety using mode S SSR p 519 A88-39495

millimeter-wave low-range altimeter helicopter applications - Experimental results

p 519 A88-39496 Measurement of multipath propagation electromagnetic waves in actual airport environments

p 506 A88-39813 Experimental investigation of topological structures in

p 486 three-dimensional separated flow A88-39970 Current rotorcraft technology advancement at MBB p 476 A88-40562

Interactive geometry definition and grid generation for applied aerodynamics [AIAA PAPER 88-2515] p 554 A88-40707

Wing vortex-flows up into vortex breakdown - A numerical simulation [AIAA PAPER 88-2518] p 487 A88-40709

Designs of profiles for cascades [NASA-TT-20161] p 547 N88-22326

Theoretical investigation of secondary instability of three-dimensional boundary-layer flows with application to the DFVLR-F5 model wing [DFVLR-FB-87-44] p 547 N88-22330

Method and device for the detection and identification of a helicopter [NASA-TT-20251]

p 556 N88-22698 Activities report of Lufthansa

[ISSN-0176-5086] p 476 N88-22855 A multilifting line method and its application in design and analysis of nonplanar wing configurations [DFVLR-FB-87-51] p 499 N88-22860

Bibliography of icing on aircraft (status 1987) [DFVLR-MITT-87-18] p 502 N88-22876

aircraft
[SAE PAPER 872333]
Lift engines - Applied history
[SAE PAPER 872347]

p 528 A88-39622

p 508 A88-37202 p 522 A88-37213

	the second secon	to the first of a set a second management require of piroraft
Digital processing of flight data of a helicopter without	Unsteady aerodynamic heating phenomena in the	Analysis of performance measurement results of aircraft.
using anti-aliasing filters	interaction of shock wave/turbulent boundary layer	II - Flight performance p 514 A88-40575
[ESA-TT-1094] p 517 N88-22890	p 486 A88-40421	Development of an airfoil of high lift/drag ratio and low
Basic design studies for the realization of liquid crystal	Status and trend in CCV p 528 A88-40526	moment coefficient for subsonic flow
display systems in aircraft	Development overview of the T-2 CCV	p 495 A88-40972
[VA-87-001] p 521 N88-22900	p 528 A88-40527	PORTUGAL
Servo-actuator control for sampled-data feedback	FBW system and control law of the T-2 CCV	The turbulence characteristics of a single impinging jet
disturbance rejection	p 528 A88-40528	through a crossflow p 545 A88-39012
[ESA-TT-1002] p 529 N88-22903		
The transonic wind tunnel (TWB) at DFVLR, Brunswick	Flight testing results of T-2 CCV p 528 A88-40529	S
(Federal Republic of Germany)	Structure and equipments of the T-2 CCV aircraft	3
[DFVLR-MITT-88-01] p 539 N88-22909	p 514 A88-40530	
	Optical technology application in aircraft	SPAIN
Evaluation of ceramic thermal barrier coatings for gas	p 474 A88-40532	A panel method based on velocity potential to compute
turbine engine components	Current trend of digital map processing	harmonically oscillating lift surface systems
[ETN-88-91947] p 543 N88-22998	p 506 A88-40533	[ETN-88-91886] p 546 N88-22290
Short duration flow establishment on a profile in a	•	SWEDEN
Water-Ludwieg-Tunnel p 549 N88-23134	Trends and problems of head-up display	Comparison of Euler and Navier-Stokes solutions for
Measurements of the time dependent velocity field	p 519 A88-40534	vortex flow over a delta wing p 485 A88-39278
surrounding a model propeller in uniform water flow	Flat panel display trends p 545 A88-40535	In-service measurements of SAAB SF-340 landing gear
p 550 N88-23155	A method to increase the accuracy of vortical flow	loads
Comparison of different kinds of compact crossflow heat	simulations	[FFA-TN-1987-48] p 516 N88-22032
exchangers	[AIAA PAPER 88-2562] p 490 A88-40736	Investigation on the movement of vortex burst position
[ESA-TT-1076] p 550 N88-23169		with dynamically changing angle of attack for a schematic
Standardized ice accretion thickness as a function of	Numerical analysis of multiple element high lift devices	with dynamically changing angle of attack for a schematic
cloud physics parameters	by Navier Stokes equation using implicit TVD finite volume	deltawing in a watertunnel with correlation to similar studies
[ESA-TT-1080] p 553 N88-23346	method	in windtunnel p 550 N88-23152
[E3A-11-1000] p 550 1100 250 15	[AIAA PAPER 88-2574] p 491 A88-40743	SWITZERLAND
_	Design method for laminar flow control of	NOTAR - The tail that wags the dog
	two-dimensional airfoils in incompressible flow. Numerical	p 510 A88-38696
•	study of LFC design concepts	X-31 - Through the grape barrier p 515 A88-41250
INDIA	[DE88-751809] p 498 N88-22859	
A survey of the flight testing and evaluation of CF M56	Analysis for high compressible supersonic flow in	<del>'T</del>
	converging nozzle	1
series turbofan	[IPPJ-860] p 500 N88-22869	
[AIAA PAPER 88-2078] p 513 A88-38763	First flight simulator test of the head-up display for NAL	TAIWAN
ILS glidescope evaluation of imperfect terrain	QSTOL experimental aircraft (ASUKA)	Numerical prediction of aerodynamic performance for
p 506 A88-39135		a low Reynolds number airfoil
Addendum-dedendum type circular-arc gears for		[AIAA PAPER 88-2575] p 491 A88-40744
aero-engine accessory drive gearbox - A critical analysis	Basic design of a flight director system for NAL STOL	TURKEY
of strength-to-weight ratio p 545 A88-40280	research aircraft	Measurements of turbulent flow behind a wing-body
Unsteady nonsimilar laminar compressible	[DE88-751806] p 521 N88-22897	junction p 484 A88-38987
boundary-layer flow over a yawed infinite circular	Flow quality of NAL two-dimensional transonic wind	Measurements in a three-dimensional turbulent
cylinder p 495 A88-40970	tunnel. Part 1: Mach number distributions, flow angularities	boundary-layer p 484 A88-39000
INTERNATIONAL ORGANIZATION	and preliminary study of side wall boundary layer suction	boundary layor processing and a second a second and a second a second and a second
Navigation and performance computer	[NASA-TT-20209] p 539 N88-22911	• •
p 519 A88-40518	JORDAN	U
	Modelling the influence of small surface discontinuities	
ISRAEL  Numerical study of the skin friction on a spheroid at	in turbulent boundary layers	U.S.S.R.
Numerical study of the skill inction on a spheroid at	[AIAA PAPER 88-2594] p 546 A88-40759	
	[AIAA FAFEN 66-2354] p 346 766 46756	
incidence p 482 A88-38376	[AIAA FAFEH 66-2394] p 346 766 40735	Numerical calculations of the natural vibrations of
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries	, , , , , , , , , , , , , , , , , , ,	turbomachine blades using the finite element method
incidence p 482 A88-38376	N	turbomachine blades using the finite element method p 523 A88-37543
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386	, , , , , , , , , , , , , , , , , , ,	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And	, , , , , , , , , , , , , , , , , , ,	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549
incidence p 482 A88-38376  IR group activities at the Israel Aircraft Industries p 474 A88-40386  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369	N	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369	NETHERLANDS Experimental and numerical investigation of the vortex	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37653  Turbulent friction on a delta wing p 480 A88-37657
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes
incidence p 482 A88-38376  IR group activities at the Israel Aircraft Industries p 474 A88-40386  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY  The use of optimization technique and through flow analysis for the design of axial flow compressor stages	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes p 544 A88-37661
incidence p 482 A88-38376  IR group activities at the Israel Aircraft Industries p 474 A88-40386  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY  The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes p 544 A88-37661 Axisymmetric turbulent compressible jet in subsonic
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369 ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes p 544 A88-37661 Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665
incidence p 482 A88-38376  IR group activities at the Israel Aircraft Industries p 474 A88-40386  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY  The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes p 544 A88-37661 Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665
incidence p 482 A88-38376  IR group activities at the Israel Aircraft Industries p 474 A88-40386  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY  The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112  Fog persistence above some airports of the north-Italian	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes p 544 A88-37661 Axisymmetric turbulent compressible jet in subsonic
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes p 544 A88-37661 Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665 Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37653  Turbulent friction on a delta wing p 480 A88-37657  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body  Radio-electronic equipment of aircraft: Handbook
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnet model [PB88-149885] p 528 N88-22038	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing p 480 A88-37657  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group  [ETN-88-92274] p 557 N88-22821	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model	turbomachine blades using the finite element method p 523 A88-37543 Life of gas turbine engine disks with cracks p 544 A88-37549 Numerical separation models p 480 A88-37653 Turbulent friction on a delta wing p 480 A88-37657 Computer simulation of turbulent jets and wakes p 544 A88-37661 Axisymmetric turbulent compressible jet in subsonic coflow Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697 Radio-electronic equipment of aircraft: Handbook p 505 A88-37699 Flight fatigue testing of helicopters
incidence p 482 A88-38376  IR group activities at the Israel Aircraft Industries p 474 A88-40386  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY  The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112  Fog persistence above some airports of the north-Italian plains p 552 A88-38372  Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group  [ETN-88-92274] p 557 N88-22821  Rapid prototyping of complex avionics systems	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing p 480 A88-37657  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821 Rapid prototyping of complex avionics system architectures	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Reliability analysis within a Computer Aided Engineering	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37549  Turbulent friction on a delta wing p 480 A88-37657  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37699  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 510 A88-37703  Information properties of complex radar
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incidence p 482 A88-38376  IR group activities at the Israel Aircraft Industries p 474 A88-40386  A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY  The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112  Fog persistence above some airports of the north-Italian plains p 552 A88-38372  Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821  Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898  Japan  Some topics of ASKA's flight test results and its future plan [SAE PAPER 872331] p 508 A88-37188  Stability and control augmentation system of 'ASKA' (SAE PAPER 872334] p 527 A88-37203  Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212 Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoll p 482 A88-38303  Flow analysis around aircraft by viscous flow computation p 482 A88-38303	NETHERLANDS  Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p. 490. A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p. 498. N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p. 528. N88-22038 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p. 547. N88-22369 Activities report in aerospace [ETN-88-91566] p. 476. N88-22866 Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence [LR-518] Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p. 517. N88-22887 Design studies of primary aircraft structures in ARALL laminates [LR-520] p. 517. N88-22888 The initial calculation of range and mission fuel during conceptual design [LR-525] p. 517. N88-22889 NEW ZEALAND  Vehicles and aircraft on floating ice p. 536. A88-40066	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 510 A88-37703  Information properties of complex radar angular-coordinate estimates p 545 A88-38448  Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate Reynolds numbers p 480 A88-40311  Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40311  Control of laminar flow around of the wing in free-air conditions  [AD-A187479] p 495 N88-22004  Model study of thermal stresses in gas-turbine blades with protective coating p 542 N88-22989  Dependence of structure of stabilized ZrOz coatings on condensation rate p 543 N88-22990  UNITED KINGDOM  Hot gas recirculation in V/STOL  [SAE PAPER 872306] p 477 A88-37178  The ground environment created by high specific thrust
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821 Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898  J JAPAN Some topics of ASKA's flight test results and its future plan [SAE PAPER 872317] p 508 A88-37188 Stability and control augmentation system of 'ASKA' [SAE PAPER 872334] p 527 A88-37203 Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212 Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil p 482 A88-38303 Flow analysis around aircraft to yiscous flow viscous flow p 482 A88-38343 Development of fiber optic data bus for aircraft	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p. 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p. 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p. 528 N88-22038 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p. 547 N88-22369 Activities report in aerospace [ETN-88-91566] p. 476 N88-22856 Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence [LR-518] p. 499 N88-22861 Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p. 517 N88-22887 Design studies of primary aircraft structures in ARALL laminates [LR-520] p. 517 N88-22888 The initial calculation of range and mission fuel during conceptual design [LR-525] p. 517 N88-22889 NEW ZEALAND Vehicles and aircraft on floating ice p. 536 A88-40066 NORWAY Simulation of transonic flow in radial compressors	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing p 480 A88-37657  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37665  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 510 A88-37703  Information properties of complex radar angular-coordinate estimates p 545 A88-38448  Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate Reynolds numbers Aerodynamics of supersonic shapes  P 486 A88-40311  Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40317  Control of laminar flow around of the wing in free-air conditions  [AD-A187479] p 495 N88-22004  Model study of thermal stresses in gas-turbine blades with protective coating p 542 N88-22990  Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990  UNITED KINGDOM  Hot gas recirculation in V/STOL  [SAE PAPER 872306] p 477 A88-37178  The ground environment created by high specific thrust vertical land aircraft
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821 Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898  J  JAPAN Some topics of ASKA's flight test results and its future plan [SAE PAPER 872317] p 508 A88-37188 Stability and control augmentation system of 'ASKA' [SAE PAPER 872334] p 527 A88-37203 Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212 Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil p 482 A88-38303 Flow analysis around aircraft by viscous flow computation p 482 A88-38344 Development of fiber optic data bus for aircraft	NETHERLANDS  Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737  Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017  Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038  Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p 547 N88-22369  Activities report in aerospace [ETN-88-91566] p 476 N88-22856  Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence [LR-518] p 499 N88-22861  Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p 517 N88-22887  Design studies of primary aircraft structures in ARALL laminates [LR-520] p 517 N88-22888  The initial calculation of range and mission fuel during conceptual design [LR-525] p 517 N88-22889  NEW ZEALAND  Vehicles and aircraft on floating ice p 536 A88-40066  NORWAY  Simulation of transonic flow in radial compressors p 480 A88-37356	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37653  Turbulent friction on a delta wing p 480 A88-37653  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 510 A88-37703  Information properties of complex radar angular-coordinate estimates p 545 A88-38448  Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate Reynolds numbers p 483 A88-38847  Aerodynamics of supersonic shapes  P 486 A88-40311  Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40314  Thermal state of a turbofan rotor Control of laminar flow around of the wing in free-air conditions [AD-A187479] p 485 N88-22990  Model study of thermal stresses in gas-turbine blades with protective coating p 542 N88-22999  Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990  UNITED KINGDOM  Hot gas recirculation in V/STOL [SAE PAPER 872309] p 477 A88-37181
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821 Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898  J JAPAN Some topics of ASKA's flight test results and its future plan [SAE PAPER 872317] p 508 A88-37188 Stability and control augmentation system of 'ASKA' [SAE PAPER 872334] p 527 A88-37203 Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212 Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil  p 482 A88-38303 Flow analysis around aircraft by viscous flow computation Development of fiber optic data bus for aircraft p 555 A88-38344 Flight test of the Japanese USB STOL experimental	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p. 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p. 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p. 528 N88-22038 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p. 547 N88-22369 Activities report in aerospace [ETN-88-91566] p. 476 N88-22856 Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence [LR-518] p. 499 N88-22861 Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p. 517 N88-22887 Design studies of primary aircraft structures in ARALL laminates [LR-520] p. 517 N88-22888 The initial calculation of range and mission fuel during conceptual design [LR-525] p. 517 N88-22889 NEW ZEALAND Vehicles and aircraft on floating ice p. 536 A88-40066 NORWAY Simulation of transonic flow in radial compressors	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 510 A88-37703  Information properties of complex radar angular-coordinate estimates p 545 A88-38448  Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate Reynolds numbers p 480 A88-40311  Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40311  Control of laminar flow around of the wing in free-air conditions  [AD-A187479] p 495 N88-22004  Model study of thermal stresses in gas-turbine blades with protective coating p 542 N88-22990  Dependence of structure of stabilized ZrOz coatings on condensation rate p 543 N88-22990  UNITED KINGDOM  Hot gas recirculation in V/STOL  [SAE PAPER 872309] p 477 A88-37181  V/STOL and the Royal Air Force
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incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821 Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898  Japan  Japan Some topics of ASKA's flight test results and its future plan [SAE PAPER 872317] p 508 A88-37188 Stability and control augmentation system of 'ASKA' (SAE PAPER 872334] p 527 A88-37203 Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212 Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil p 482 A88-38303 Flow analysis around aircraft by viscous flow computation p 482 A88-38344 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Aircraft observation of the specific humidity and process of the water vapor transfer in the upper mixed boundary	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p 547 N88-22369 Activities report in aerospace [ETN-88-91566] p 476 N88-22856 Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence [LR-518] Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p 517 N88-22887 Design studies of primary aircraft structures in ARALL laminates [LR-520] The initial calculation of range and mission fuel during conceptual design [LR-525] p 517 N88-22889 NEW ZEALAND Vehicles and aircraft on floating ice p 536 A88-40066 NORWAY Simulation of transonic flow in radial compressors p 480 A88-37356	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 545 A88-37703  Information properties of complex radar angular-coordinate estimates p 545 A88-38448  Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate Reynolds numbers p 480 A88-40317  Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40317  Control of laminar flow around of the wing in free-air conditions  [AD-A187479] p 495 N88-22004  Model study of thermal stresses in gas-turbine blades with protective coating p 542 N88-22990  Dependence of structure of stabilized ZrOz coatings on condensation rate p 543 N88-22990  UNITED KINGDOM  Hot gas recirculation in V/STOL  [SAE PAPER 872309] p 477 A88-37181  V/STOL and the Royal Air Force  [SAE PAPER 872319] p 508 A88-37189  The VAAC VSTOL [flight control research project  [SAE PAPER 872331] p 526 A88-37200
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821 Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898  J JAPAN Some topics of ASKA's flight test results and its future plan [SAE PAPER 872317] p 508 A88-37188 Stability and control augmentation system of 'ASKA' [SAE PAPER 872334] p 527 A88-37203 Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212 Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil p 482 A88-38303 Flow analysis around aircraft by viscous flow computation Development of fiber optic data bus for aircraft p 555 A88-38344 Flight test of the Japanese USB STOL experimental aircraft ASKA IAIAA PAPER 88-2180] p 513 A88-38750 Aircraft observation of the specific humidity and process of the water vapor transfer in the upper mixed boundary layer p 552 A88-39508	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p 547 N88-22369 Activities report in aerospace [ETN-88-91566] p 476 N88-22856 Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence [LR-518] p 499 N88-22861 Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p 517 N88-22887 Design studies of primary aircraft structures in ARALL laminates [LR-520] p 517 N88-22888 The initial calculation of range and mission fuel during conceptual design [LR-525] p 517 N88-22889 NEW ZEALAND Vehicles and aircraft on floating ice p 536 A88-40066 NORWAY Simulation of transonic flow in radial compressors p 480 A88-37356	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing p 480 A88-37657  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 510 A88-37703  Information properties of complex radar angular-coordinate estimates p 545 A88-38448  Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate Reynolds numbers p 483 A88-38847  Aerodynamics of supersonic shapes  Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40314  Thermal state of a turbofan rotor p 545 A88-30314  Thermal state of a turbofan rotor p 545 A88-40314  Thermal state of a turbofan rotor p 546 A88-40314  Thermal state of a turbofan rotor p 547 A88-37189  Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990  UNITED KINGDOM  Hot gas recirculation in V/STOL  [SAE PAPER 872306] p 477 A88-37181  V/STOL and the Royal Air Force  [SAE PAPER 872319] p 508 A88-37189  The VAAC VSTOL flight control research project  [SAE PAPER 872331] p 508 A88-37200  Propulsion/aerodynamic integration in ASTOVL combat aircraft
incidence p 482 A88-38376 IR group activities at the Israel Aircraft Industries p 474 A88-40386 A lightweight innovative Helmet Airborne Display And Sight (HADAS) p 520 A88-41369  ITALY The use of optimization technique and through flow analysis for the design of axial flow compressor stages p 477 A88-37112 Fog persistence above some airports of the north-Italian plains p 552 A88-38372 Information systems for quality. Experience at the Nerviano Aeritalia plant. Avionic systems and equipment group [ETN-88-92274] p 557 N88-22821 Rapid prototyping of complex avionics system architectures [ETN-88-92275] p 521 N88-22898  Japan  Japan Some topics of ASKA's flight test results and its future plan [SAE PAPER 872317] p 508 A88-37188 Stability and control augmentation system of 'ASKA' (SAE PAPER 872334] p 527 A88-37203 Numerical simulation of compressible flow field about complete ASKA aircraft configuration [SAE PAPER 872346] p 478 A88-37212 Improvements on accuracy and efficiency for calculation of transonic viscous flow around an airfoil p 482 A88-38303 Flow analysis around aircraft by viscous flow computation p 482 A88-38344 Flight test of the Japanese USB STOL experimental aircraft ASKA [AIAA PAPER 88-2180] p 513 A88-38750 Aircraft observation of the specific humidity and process of the water vapor transfer in the upper mixed boundary	NETHERLANDS Experimental and numerical investigation of the vortex flow over a yawed delta wing [AIAA PAPER 88-2563] p 490 A88-40737 Trends in Computational Fluid Dynamics (CFD) for aeronautical 3D steady applications: The Dutch situation [NLR-MP-86074-U] p 498 N88-22017 Design of an integrated control system for flutter margin augmentation and gust load alleviation, tested on a dynamic windtunnel model [PB88-149885] p 528 N88-22038 Reliability analysis within a Computer Aided Engineering (CAE) infrastructure [NLR-MP-86059-U] p 547 N88-22369 Activities report in aerospace [ETN-88-91566] p 476 N88-22856 Experimental investigation of the transonic flow at the leeward side of a delta wing at high incidence [LR-518] Development of a flexible and economic helicopter engine monitoring system [PB88-165147] p 517 N88-22887 Design studies of primary aircraft structures in ARALL laminates [LR-520] The initial calculation of range and mission fuel during conceptual design [LR-525] p 517 N88-22889 NEW ZEALAND Vehicles and aircraft on floating ice p 536 A88-40066 NORWAY Simulation of transonic flow in radial compressors p 480 A88-37356	turbomachine blades using the finite element method p 523 A88-37543  Life of gas turbine engine disks with cracks p 544 A88-37549  Numerical separation models p 480 A88-37657  Turbulent friction on a delta wing p 480 A88-37657  Computer simulation of turbulent jets and wakes p 544 A88-37661  Axisymmetric turbulent compressible jet in subsonic coflow p 480 A88-37665  Separation of a supersonic boundary layer ahead of the base of a body p 480 A88-37697  Radio-electronic equipment of aircraft: Handbook p 505 A88-37699  Flight fatigue testing of helicopters p 510 A88-37703  Information properties of complex radar angular-coordinate estimates p 545 A88-38448  Analytical study of friction and heat transfer in the vicinity of a three-dimensional critical point at low and moderate Reynolds numbers p 483 A88-38847  Aerodynamics of supersonic shapes  Factors affecting the temperature state of the blading of high-temperature turbines p 486 A88-40314  Thermal state of a turbofan rotor p 545 A88-30314  Thermal state of a turbofan rotor p 545 A88-40314  Thermal state of a turbofan rotor p 546 A88-40314  Thermal state of a turbofan rotor p 547 A88-37189  Dependence of structure of stabilized ZrO2 coatings on condensation rate p 543 N88-22990  UNITED KINGDOM  Hot gas recirculation in V/STOL  [SAE PAPER 872306] p 477 A88-37181  V/STOL and the Royal Air Force  [SAE PAPER 872319] p 508 A88-37189  The VAAC VSTOL flight control research project  [SAE PAPER 872331] p 508 A88-37200  Propulsion/aerodynamic integration in ASTOVL combat aircraft

Applying v		thrust	V/STOL	ex	perience	in
supersonic de						
[SAE PAPER				509	A88-372	230
A supersoni		with V/				
SAE PAPER				509	A88-372	231
Overview of		UK AST	OVL prog	ıram		
(SAE PAPER				473	A88-372	
Recent dev			engineerin	g ap	plications	of
the vortex clos				480	A88-373	
Adaptive wa	II researc	h with t	wo- and th	hree	-dimensio	nal
models in low			onic tunne	els		
(AIAA PAPER				533	A88-379	39
On the pros	pects for	increas	ing dynan	nic li	ft	
				481	A88-381	
Wind tunnel				two	-dimensio	nal
aerofoil motion				535	A88-381	69
Flow in out-	of-plane (	double S	S-bends			
				484	A88-390	
The calculat	ion of the	e flow t	hrough a	two	-dimensio	nal
faired diffuser			p 4	485	A88-390	
Cool Europe				524	A88-392	76
V-22 Osprey	/ - Chang	ing the				
				514		
Prediction o	f vortex	lift of n				
leading-edge s		alogy		185		
Tupolev Bac				514		
The role of i						SS
certification of	civil aircr	aft com				
				545	A88-401	
The use of sr						
rotor blade vib	ration stu	dies	р 5	15	A88-412	22
Flexiwall 3 S	SO: A sec	ond or	der predic	tive	strategy	for
rapid wall adj	ustment	in two-	dimension	ai c	ompressit	ole
flow						
[NASA-CR-181				98		
The use of i	rule induc	tion to	assist in t	the o	diagnosis	of
avionic circuit t		ects	_			
[ETN-88-92077			p 5		N88-228	
Measuremen						
moving bluff pa					N88-231	
Water flow	visualisa	ition of				
chamber			p 5	49	N88-231	38

#### Y

YUGOSLAVIA

Decentralized approach to the design of automatic flight control systems

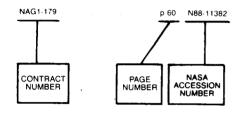
p 528 A88-40858

## **CONTRACT NUMBER INDEX**

#### AERONAUTICAL ENGINEERING / A Continuing Bibliography (Supplement 230)

September 1988

## Typical Contract Number Index Listing



Listings in this index are arranged alphanumerically by contract number. Under each contract number, the accession numbers denoting documents that have been produced as a result of research done under that contract are arranged in ascending order with the AIAA accession numbers appearing first. The accession number denotes the number by which the citation is identified in the abstract section. Preceding the accession number is the page number on which the citation may be found.

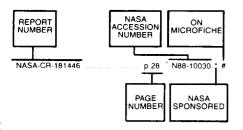
.= .====		
AF AFOSR-0239-85	p 554	N88-22691
AF AFOSR-0286-84	p 541	N88-22121
AF-AFOSR-0305-86	p 525	N88-22036
AF-AFOSR-0308-85	p 546	N88-22300
AF-AFOSR-0324-86	p 496	N88-22007
AF-AFOSR-77-3233	p 480	A88-37360
AF-AFOSR-79-0023	p 480	A88-37360
AF-AFOSR-84-0184	p 535	A88-37949
AF-AFOSR-85-0126	p 484	A88-39023
BMFT-LFL-8376-0	p 521	N88-22900
DA PROJ. 1L1-61102-AH-45-C	p 542	N88-22949
DA PROJ. 1L1-61102-AH-45	p 551	N88-23220
DAAG29-83-K-0002	p 546	A88-40871
DAAG29-85-C-0002	p 501	N88-22874
DE-AC04-76DP-00789	p 538	N88-22907
DE-AC05-84OR-21400	p 538	N88-22046
DRET-83-403	p 495	A88-41269
DRET-85-053	D 556	N88-22713
DRET-85-115	p 491	A88-40742
DTFA03-84-C-0004	p 515	N88-22024
F33615-83-C-2352	p 543	N88-23011
F33615-83-C-3215	p 480	A88-37360
F33615-84-C-2424	p 546	N88-22276
F33615-84-C-2431	p 515	N88-22025
F33615-84-C-3005	p 487	A88-40708
F33615-84-C-3015	p 510	A88-37232
F33615-84-C-5017	p 542	N88-22954
F33615-85-C-3619	p 549	N88-23130
F33615-86-C-3200	p 501	N88-22875
F33615-86-D-3800	p 539	N88-22912
F33651-81-C-2011	p 524	A88-39133
F40600-85-C-0002	p 531	A88-37909
F49620-83-K-0009	p 492	A88-40750
F49620-84-C-0007	p 486	A88-39967
F49620-84-C-0086	p 486	A88-39952
F49620-85-C-0013	p 492	A88-40748
E.0000 05 0 0000	p 492	A88-40751
F49620-85-C-0055	p 478	A88-37211
F49620-85-C-0115	p 547	N88-22305
F49620-86-K-0022	p 541	N88-22115
F49620-87-C-0004	p 496	N88-22008
F49620-87-C-0069	p 493	A88-40760
NAGW-1072	p 493	A88-40757
NAGW-747	p 484	A88-39011
NAG1-226	p 491	A88-40747
NAG1-344	p 489	A88-40731
NAG1-363	p 479	A88-37355
NAG1-390	p 556	A88-39725
NAG1-417	p 534	A88-37944
NAG1-490 NAG1-545	p 507	N88-22884
NAG1-545	p 484	A88-39023

NAG1-633	n	493	A88-40762
NAG1-716		481	A88-37919
	ρ	532	A88-37920
NAG1-727	'n	489	A88-40735
NAG1-729	Р	550	N88-23160
NAG1-735	р	545	A88-40713
NAG1-819	'n	497	N88-22011
NAG2-258		482	A88-38377
NAG2-297	p	529	N88-22904
NAG2-471		517	N88-22891
NAG3-499		501	N88-23245
NAG3-621	р	533	A88-37926
NAG3-724	D	501	N88-23248
NAG3-730		530	N88-23249
NASA ORDER A-56829-C		493	A88-40756
NASA TASK 32	р	537	A88-40721
NASW-4307	D	547	N88-22326
		556	N88-22698
	p:	539	N88-22911
NAS1-15780	р	554	N88-23472
NAS1-17919	n!	514	A88-40711
		537	
			A88-40721
NAS1-18004	р :	507	N88-22886
NAS1-18020		556	N88-23545
11104 40407		554	
			N88-23519
NAS1-18235		494	A88-40765
NAS1-7999	р	485	A88-39511
		485	A88-39512
NAC1 0007			
NAS1-9987		485	A88-39511
	p 4	485	A88-39512
NAS2-10791	'n	500	N88-22866
			N88-22867
		500	
	р :	500	N88-22868
NAS2-11310	p f	557	N88-23548
NAS2-11753		518	N88-22893
NAS2-11853		521	N88-22901
NAS2-12243	p 4	193	A88-40756
NAS3-23288	p. 5	548	N88-22426
*****		525	N88-22394
11100 00700			
NAS3-23708		554	A88-37219
NAS3-23939	р 5	542	N88-22427
NAS3-24080	n f	523	A88-37947
NAS3-24105		25	N88-22384
	р 5	526	N88-23247
NAS3-24621	p 4	178	A88-37220
		555	A88-37221
11400 04055			
NAS3-24855		188	A88-40718
NAS8-33108	p 5	43	A88-37108
NCC2-294		183	A88-38985
	p -		
	р 5		N88-22045
	p 5	51	N88-23171
NCC2-341	p 4	89	A88-40734
NCC2-403			A88-37209
NCC2-416	р 4		A88-40601
NCC3-46	р 5	48	N88-22418
NGT-34-002-801	p 4		A88-40757
NSG-7172			A88-37939
	p 4		N88-22865
NSG-7523	р 5	32	A88-37920
NSG7-172			N88-22018
N00014-83-C-0694			
			N88-22006
N00014-85-K-0604			N88-22870
N00014-85-K-0665	p 5	47	NB8-22320
N00228-85-G-3262			N88-22706
NG0001 92 C A166 D00			
N60921-63-C-A165-B02		04	A88-38988
STU-84-4563	p5	16	N88-22032
505-42-11	p 5	57	N88-23548
505-43-01			N88-22866
	p 5		N88-22867
	p 5		N88-22868
505-60-01	p 4	97	N88-22010
	p 4		N88-22014
505-60-11			
			N88-22864
505-60-21-01	p5	50	N88-23160
505-60-21			N88-22012
505-60-31-03			N88-22047
505-61-01-02	р4	98	N88-22018
	p 4	99	N88-22865
EOE 61 11			
			N88-23548
505-61-11	p5	37	1100 20040
505-61-51-06	р5 р5		
505-61-51-06	р5	56	N88-22710
505-61-51-06 505-61-51-10	p5 p4	56 97	N88-22710 N88-22015
505-61-51-06	р5	56 97	N88-22710
505-61-51-06	p5 p4 p4	56 97 99	N88-22710 N88-22015

NAG1-633 ...... p 493 A88-40762

505-61-71-01	p 497	N88-22016
505-62-38	p 525	N88-22037
505-63-01-05	p 542	N88-22949
505-63-1B	p 548	N88-22382
	p 549	N88-22446
	p 551	N88-23226
505-63-51-01	p 548	N88-22434
505-63-51-10	p 517	N88-22892
505-63-71	p 551	N88-23220
505-66-01-02	p 507	N88-22886
	p 554	N88-23463
505-66-21-03	p 554	N88-23472
505-90-21-01	p 554	N88-23519
506-40-21-01	p 547	N88-22325
506-43-41-01	p 516	N88-22031
533-02-51	p 518	N88-22893
535-03-01	p 526	N88-22902
535-03-11-03	p 556	N88-23545
	p 557	N88-23547
545-03-01	p 498	N88-22019
922-22-08	p 516	N88-22033
992-21-01	p 529	N88-22905

#### Typical Report Number Index Listing



Listings in this index are arranged alphanumerically by report number. The page number indicates the page on which the citation is located. The accession number denotes the number by which the citation is identified. An asterisk (\*) indicates that the item is a NASA report. A pound sign (#) indicates that the item is available on microfiche.

A-87098		r	497	N88-22013	• #
A-87288	*************************************	. [	497	N88-22010	٠,
			497	N88-22014	
			529	N88-22905	
				N88-22864	
	•••••		499		- "
A-88142	•••••	F	496	N88-22009	* #
AAS PAPER	87-127	F	540	A88-41288	٠
AD-A187479	***************************************	p	495	N88-22004	Ħ
AD-A189644		p	528	N88-22039	Ħ
AD-A189690		p	541	N88-22115	Ħ
AD-A189715		p	515	N88-22022	Ħ
AD-A189848	***************************************	p	529	N88-22040	Ħ
AD-A189871		р	496	N88-22005	#
AD-A189873		р	515	N88-22023	#
AD-A189928		p	546	N88-22300	#
AD-A189962	***************************************	p	515	N88-22024	#
AD-A189966	***************************************	р	556	N88-22702	#
AD-A189985		р	546	N88-22276	#
AD-A189986		р	476	N88-22003	#
AD-A190106		р	524	N88-22034	#
AD-A190110		р	524	N88-22035	#
AD-A190120			543	N88-23011	#
AD-A190128			496	N88-22006	#
AD-A190136		р	496	N88-22007	#
AD-A190245			547	N88-22305	#
AD-A190254	***************************************		556	N88-22706	#
AD-A190336			525	N88-22036	#
AD-A190406			541	N88-22121	#
AD-A190408			515	N88-22025	#
AD-A190484		•	537	N88-22043	#
AD-A190490	***************************************		496	N88-22008	#
AD-A190520			529	N88-22041	#
AD-A190538			554	N88-22691	#
AD-A190568	***************************************		537	N88-22044	#
AD-A190576			552	N88-22496	#
AD-A190604			516	N88-22029	#
AD-A190613	***************************************		542	N88-22940	#
AD-A190614			529	N88-22042	#
AD-A190617			541	N88-22092	#
AD-A190674			516	N88-22030	#
AD-A190772			547	N88-22320	#
AD-A190838	***************************************		539	N88-22912	#
AD-A190856	•••••		500	N88-22870	#
AD-A190998			542	N88-22954	#
AD-A191279			518	N88-22894	#
AD-A191314			530	N88-22906	#
AD-A191336	***************************************		501	N88-22874	#
AD-A191407			543	N88-23009	#
AD-A191408			501	N88-22875	#
AD-A191414		р	518	N88-22895	#
AFIT/GA/AA/	/87D-10	_	524	N88-22035	ш
	/87D-10/88M-2		542	N88-22940	#

AFIT/GA/AA/88M-2 ..... p 542 N88-22940

AFIT/GA/AA/88M-3	•••••	. р 541	N88-22092	. #
AFIT/GAE/AA/87S-2		. p 528	N88-22039	· #
AFIT/GCE/ENG/87D- AFIT/GCE/ENG/87D-				
AFIT/GE/ENG/87D-4	0	. p 515		#
AFIT/GE/ENG/87D-5				
AFIT/GE/ENG/87D-6 AFIT/GE/ENG/87D-6				
AFIT/GE/ENG/88M-3		. р 523 . р 537		
AFOSR-87-1763TR AFOSR-87-1769TR				
				# #
				#
AFOSR-87-1910TR-P1			N88-22305	Ħ
AFWAL-TR-86-2073 AFWAL-TR-87-2043-V		p 546		
AFWAL-TR-87-2060-V				#
AFWAL-TR-87-3097		p 501	N88-22875	#
AFWAL-TR-87-3115-V				#
AFWAL-TR-87-4116				#
AIAA PAPER 88-0187 AIAA PAPER 88-1996			A88-41092 A88-37909	#
AIAA PAPER 88-1997			A88-37910	• #
AIAA PAPER 88-1999		p 531	A88-37911	* #
AIAA PAPER 88-2001	***************************************		A88-37912	#
AIAA PAPER 88-2002 AIAA PAPER 88-2003			A88-37913 A88-37914	#
AIAA PAPER 88-2004			A88-37915	#
AIAA PAPER 88-2007			A88-37916	#
AIAA PAPER 88-2008 AIAA PAPER 88-2010			A88-37917 A88-37918	* #
AIAA PAPER 88-2011			A88-37919	* #
AIAA PAPER 88-2012		p 532	A88-37920	
AIAA PAPER 88-2013			A88-37921	* #
AIAA PAPER 88-2014 AIAA PAPER 88-2019			A88-37922 A88-37926	* #
AIAA PAPER 88-2024			A88-37929	
AIAA PAPER 88-2025		p 544	A88-37930	
AIAA PAPER 88-2027 AIAA PAPER 88-2029			A88-37931 A88-37932	* #
AIAA PAPER 88-2030			A88-37933	#
AIAA PAPER 88-2033		p 533	A88-37936	* #
AIAA PAPER 88-2035 AIAA PAPER 88-2036			A88-37937 A88-37938	
AIAA PAPER 88-2037			A88-37938 A88-37939	
AIAA PAPER 88-2038		p 534	A88-37940	#
AIAA PAPER 88-2039 AIAA PAPER 88-2040			A88-37941	#
AIAA PAPER 88-2041		p 534	A88-37942 A88-37943	#
AIAA PAPER 88-2044		p 534	A88-37944	
AIAA PAPER 88-2045			A88-39525	#
AIAA PAPER 88-2048 AIAA PAPER 88-2056			A88-37945 A88-37946	* #
AIAA PAPER 88-2057			A88-37947	• #
AIAA PAPER 88-2062		p 535	A88-37949	#
AIAA PAPER 88-2063 AIAA PAPER 88-2075		p 535 p 510	A88-37950 A88-38702	. #
AIAA PAPER 88-2076		p 511	A88-38702	* #
AIAA PAPER 88-2077		p 511	A88-38704	#
AIAA PAPER 88-2078		p 513	A88-38763	#
AIAA PAPER 88-2082 AIAA PAPER 88-2085		p 505 p 518	A88-38705 A88-38707	# *#
AIAA PAPER 88-2087		p 536	A88-38761	• #
AIAA PAPER 88-2092		p 511	A88-38709	#
AIAA PAPER 88-2094 AIAA PAPER 88-2095		p 473	A88-38710 A88-38711	* #
AIAA PAPER 88-2096		p 535 p 535	A88-38712	• #
AIAA PAPER 88-2098		p 536	A88-38713	#
AIAA PAPER 88-2102		p 505	A88-38714	#
AIAA PAPER 88-2103 AIAA PAPER 88-2110		p 519 p 513	A88-38715 A88-38762	* #
AIAA PAPER 88-2118		p 513	A88-38719	* # #
AIAA PAPER 88-2119		p 505	A88-38720	#
AIAA PAPER 88-2120		p 511	A88-38721	#
AIAA PAPER 88-2121		p 511	A88-38722	#
AIAA PAPER 88-2123		n 474	A88-38723	#

AIAA PAPER 88-2123 ..... p 474 A88-38723

AIAA PAPER 88-2125		. p 553	A88-38725
AIAA PAPER 88-2126		•	A88-38726
AIAA PAPER 88-2127			A88-38727
AIAA PAPER 88-2128 AIAA PAPER 88-2129			A88-38728
AIAA PAPER 88-2130			A88-38729 A88-38730
AIAA PAPER 88-2134			A88-38731 *
AIAA PAPER 88-2139			A88-38735
AIAA PAPER 88-2143 AIAA PAPER 88-2144			A88-38736 A88-38737 *
AIAA PAPER 88-2145			A88-38738 *
AIAA PAPER 88-2150			A88-38740
AIAA PAPER 88-2165		•	A88-38743
AIAA PAPER 88-2167 AIAA PAPER 88-2168			A88-38744 * A88-38745 *
AIAA PAPER 88-2171			A88-38746
AIAA PAPER 88-2172		p 553	A88-38765 *
AIAA PAPER 88-2174			A88-38766
AIAA PAPER 88-2175 AIAA PAPER 88-2177		p 527 p 513	A88-38747 * A88-38748
AIAA PAPER 88-2179			A88-38749
AIAA PAPER 88-2180		p 513	A88-38750
AIAA PAPER 88-2182 AIAA PAPER 88-2184		p 474	A88-38752
AIAA PAPER 88-2185		p 474 p 474	A88-38753 A88-38754
AIAA PAPER 88-2187		p 557	A88-38755
AIAA PAPER 88-2190		p 502	A88-38756
AIAA PAPER 88-2268 AIAA PAPER 88-2401		p 514	A88-40868 A88-40871
AIAA PAPER 88-2507		p 546 p 487	A88-40702
AIAA PAPER 88-2510		p 494	A88-40766 *
AIAA PAPER 88-2511		p 514	A88-40704
AIAA PAPER 88-2513 AIAA PAPER 88-2514		p 487 p 528	A88-40705 A88-40706 *
AIAA PAPER 88-2515		p 554	A88-40707
AIAA PAPER 88-2516		p 493	A88-40762 *
AIAA PAPER 88-2517	***************************************	p 487	A88-40708
AIAA PAPER 88-2518 AIAA PAPER 88-2521		p 487 p 514	A88-40709 ;
AIAA PAPER 88-2522		p 487	A88-40712
AIAA PAPER 88-2523		p 545	A88-40713 * ;
AIAA PAPER 88-2524 AIAA PAPER 88-2527		p 488 p 488	A88-40714 A88-40716
AIAA PAPER 88-2530		p 488	A88-40716 ;
AIAA PAPER 88-2532		p 488	A88-40718 * ;
AIAA PAPER 88-2537 AIAA PAPER 88-2538		p 537	A88-40721 * ;
AIAA PAPER 88-2539		p 537 p 537	A88-40722 * ;
AIAA PAPER 88-2546		p 488	A88-40728
AIAA PAPER 88-2547		p 488	A88-40729 #
AIAA PAPER 88-2548 AIAA PAPER 88-2549		p 489 p 489	A88-40730 # A88-40731 * #
AIAA PAPER 88-2552		p 489	A88-40732 #
AIAA PAPER 88-2553		p 494	A88-40763 * #
AIAA PAPER 88-2554 AIAA PAPER 88-2556		p 494 p 489	A88-40764 * # A88-40733 #
AIAA PAPER 88-2558		p 489	A88-40733 # A88-40734 * #
AIAA PAPER 88-2559		p 489	A88-40735 * #
AIAA PAPER 88-2560 AIAA PAPER 88-2562		p 494	A88-40767 * #
AIAA PAPER 88-2563		p 490 p 490	A88-40736 # A88-40737 #
AIAA PAPER 88-2565		p 490	A88-40738 #
AIAA PAPER 88-2566		p 490	A88-40739 * #
AIAA PAPER 88-2570 AIAA PAPER 88-2571	***************************************	p 490	A88-40741 #
AIAA PAPER 88-2572		p 491 p 494	A88-40742 # A88-40765 * #
AIAA PAPER 88-2573		p 495	A88-41048 #
AIAA PAPER 88-2574		p 491	A88-40743 #
AIAA PAPER 88-2575 AIAA PAPER 88-2576		p 491 p 491	A88-40744 # A88-40745 * #
AIAA PAPER 88-2577		p 491	A88-40745 * # A88-40746 #
AIAA PAPER 88-2578		p 491	A88-40747 * #
AIAA PAPER 88-2579		p 492	A88-40748 #
AIAA PAPER 88-2580 AIAA PAPER 88-2581		p 492 p 492	A88-40749 # A88-40750 #
AIAA PAPER 88-2582		p 492	A88-40751 #
AIAA PAPER 88-2583		p 492	A88-40752 * #
AIAA PAPER 88-2586 AIAA PAPER 88-2587		p 493	A88-40755 #
AIAA PAPER 88-2590		р 493 р 495	A88-40756 * # A88-40771 #

.....p 546 A88-40759

AIAA PAPER 88-2594

#### **AIAA PAPER 88-2595**

AIAA PAPER 88-2595 AIAA PAPER 88-2597 AIAA PAPER 88-2599								
AIAA PAPER 88-2597	p 493	A88-40760 #	FTD-ID(RS)T-1042-87	p 495	N88-22004 #	NAS 1.55:3003-VOL-2	p 548	
AIAA 770 E11 00 2007	p 494		, ,			NAS 1.60:2784	p 556	N88-22710 * #
AIAA PAPEH 88-2599	p 493	A88-40761 #	H-1439	p 516	N88-22033 * #	NAS 1.60:2804	p 547	N88-22325 * #
70707170 211 00 2000			H-1454	p 538	N88-22050 * #	NAS 1.60:2808	p 516	N88-22031 * #
AIAA-88-2087	p 506	N88-22883 * #	H-1456	p 506	N88-22883 * #	NAS 1.77:20161	p 547	N88-22326 * #
AIAA-88-2216	p 538	N88-22050 * #				NAS 1.77:20209		
AIAA-88-2963	p 525	N88-22037 * #	ICASE-88-30	p 554	N88-23519 * #	NAS 1.77:20251	p 556	N88-22698 * #
AIAA-88-2979	p 551	N88-23220 * #					- 554	N88-23226 * #
			IPPJ-860	p 500	N88-22869 #	NASA-CP-3003-VOL-1		
AVSCOM-TM-88-B-006	p 497	N88-22015 * #				NASA-CP-3003-VOL-2	p 548	N88-22382 * #
AVSCOM-TM-88-B-007	p 499	N88-22863 * #	ISL-CO-247/86	p 556	N88-22713 #		- 510	NIGO 22002 * #
AVSCOM-TM-88-B-010	p 548	N88-22434 * #				NASA-CR-177330		N88-22893 * #
			ISSN-0171-1342	p 547	N88-22330 #	NASA-CR-177343-VOL-1		N88-22866 * # N88-22867 * #
AVSCOM-TR-87-B-3	p 556	N88-22710 * #	ISSN-0171-1342	p 499	N88-22860 #	NASA-CR-177343-VOL-2		
AVSCOM-TR-87-C-37	p 551	N88-23220 * #	ISSN-0176-5086	. p 476	N88-22855	NASA-CR-177343-VOL-4		N88-22868 * # N88-23548 * #
			ISSN-0176-7739	p 502	N88-22876 #	NASA-CR-177355		N88-23472 * #
B8731726	p 498	N88-22017 #	ISSN-0176-7739	. p 539	N88-22909 #	NASA-CR-181641		N88-22018 * #
B8733100	p 547	N88-22369 #	ISSN-0469-4732	. p 500	N88-22869 #	NASA-CR-181662		N88-22886 * #
B8733276	p 517	N88-22889 #				NASA-CR-181664		N88-23519 * #
B8733283	p 499	N88-22861 #	JAIA-TR-87-01	. р 501	N88-22874 #	NASA-CR-181665 NASA-CR-182747		N88-22045 * #
B8733286	p 517	N88-22888 #				NASA-CR-182759		N88-22011 * #
			JIAA-TR-84	. р 537	N88-22045 * #	NASA-CR-182867		N88-22904 * #
CONF-880160-4	p 538	N88-22907 #				NASA-CR-182874		N88-23171 * #
CONF-880461-1	p 538	N88-22046 #	KU-FRL-671-1	. p 507	N88-22884 * #	NASA-CR-182879		N88-22891 * #
						NASA-CR-182892	n 521	N88-22901 * #
DE88-002612	p 538	N88-22046 #	L-16346	. p 547	N88-22325 * #	NASA-CR-182896		N88-22884 * #
DE88-006644	p 538	N88-22907 #	L-16354	. p 556	N88-22/10 * #	NASA-CR-4128		N88-22865 * #
DE88-751804	p 521	N88-22896 #	L-16387	. p 538	N88-22047 " #	NASA-CR-4137		N88-23545 * #
DE88-751806	p 521	N88-22897 #	L-16418	. p 516	N88-22031 * #	NASA-CR-4142	p 550	N88-23160 * #
DE88-751809	p 498	N88-22859 #		. 500	NOO 00004 * #	TACA-CIT-11-E	F	
			LIDS-TH-1770	. p 529	N88-22904 * #	NASA-TM-100009	n 497	N88-22010 * #
DFVLR-FB-86-08	p 529	N88-22903 #			1100 00004 #	NASA-TM-100078		N88-22905 * #
DFVLR-FB-86-63	p 550	N88-23169 #	LR-31114	. p 515	N88-22024 #	NASA-TM-100083		N88-22014 * #
DFVLR-FB-87-08	p 553	N88-23346 #	LR-518	. p 499	N88-22861 #	NASA-TM-100090		N88-22864 * #
DFVLR-FB-87-44	p 547	N88-22330 #	LR-520	. p 517	N88-22888 # N88-22889 #	NASA-TM-100095	p 496	N88-22009 * #
DFVLR-FB-87-51	p 499	N88-22860 #	LR-525	. p 51/	N88-22889 #	NASA-TM-100172		N88-22851 * #
		"			N88-22008 #	NASA-TM-100279		N88-22446 * #
DFVLR-MITT-87-12	p 517	N88-22890 #	MDC-K0535	. р 496	1488-22006 #	NASA-TM-100415	p 516	N88-22033 * #
DFVLR-MITT-87-18	p 502	N88-22876 #		- 540	NOD 02000 #	NASA-TM-100424		N88-22050 * #
DFVLR-MITT-88-01	p 539	N88-22909 #	NADC-87171-60	р 543	N88-23009 #	NASA-TM-100428		N88-22883 * #
		NIDD 00000 #	NAE-AN-48	n E10	N88-22894 #	NASA-TM-100529	p 497	N88-22016 * #
DOT-TSC-FAA-87-5	p 4/6	N88-22003 #	NAE-AN-48	рэто	1100-22034 #	NASA-TM-100543	p 497	N88-22015 * #
	n F01	NIGO 22001 * #	NAL-TM-554	n 521	N88-22896 #	NASA-TM-100544		N88-22863 * #
DOT/FAA/CT-86/32 DOT/FAA/CT-87/13	p 521	N88-22024 #	NAL-TM-558	p 521		NASA-TM-100548	p 542	N88-22949 * #
DOT/FAA/C1-8//13	рэгэ	1400-22024 #	MAC-114-550	p 02.	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	NASA-TM-100569		N88-22892 * #
DOT/FAA/PM-87/27	n 539	N88-22912 #	NAL-TR-693	р 539	N88-22911 * #	NASA-TM-100583		N88-22434 * #
DOT/FAA/FW-07/27	<b>p</b> 000	1100 220 12 1/	NAL-TR-920	p 498	N88-22859 #	NASA-TM-100588		N88-22012 * #
D180-30344-2-VOL-2	n 515	N88-22025 #	TOTAL TITLE OF THE STATE OF THE			NASA-TM-100595		
D180-30344-2-VOL-2	<b>p</b> 0.0		NAS 1.15:100009	p 497	N88-22010 * #	NASA-TM-100609		
	n 558	N88-22851 * #	NAS 1 15:100078	p 529	N88-22905 * #	NASA-TM-100612	. p 557	N88-23547 * #
	- 540	N88-22446 * #	NAS 1.15:100083	n 497	N88-22014 * #	NASA-TM-100873	. р 498	N88-22019 * #
E-3740	D 549	1986-22440 #						N88-22037 #
E-3920	p 549 p 551	N88-23226 * #	NAS 1.15:100090	p 499	N88-22864 * #	NASA-TM-100887	. p 525	1100 22000 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2	p 551 p 548	N88-23226 * # N88-22382 * #	NAS 1.15:100090 NAS 1.15:100095	p 499 p 496	N88-22864 * # N88-22009 * #	NASA-TM-100891	. p 526	N88-22902 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099	p 551 p 548 p 498	N88-23226 * # N88-22382 * # N88-22019 * #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172	p 499 p 496 p 558	N88-22864 * # N88-22009 * # N88-22851 * #	NASA-TM-100891 NASA-TM-100918	. р 526 . р 551	N88-22902 * # N88-23220 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099	p 551 p 548 p 498	N88-23226 * # N88-22382 * # N88-22019 * #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279	p 499 p 496 p 558 p 549	N88-22864 * # N88-22009 * # N88-22851 * # N88-22446 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126	. р 526 . р 551 . р 499	N88-22902 * # N88-23220 * # N88-22862 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120	p 551 p 548 p 498 p 525 p 526	N88-23226 * # N88-22382 * # N88-22019 * # N88-22037 * # N88-22902 * #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415	p 499 p 496 p 558 p 549 p 516	N88-22864 * # N88-22009 * # N88-22851 * # N88-22446 * # N88-22033 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032	. p 526 . p 551 . p 499 . p 538	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120	p 551 p 548 p 498 p 525 p 526	N88-23226 * # N88-22382 * # N88-22019 * # N88-22037 * # N88-22902 * #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415	p 499 p 496 p 558 p 549 p 516 p 538	N88-22864 * # N88-22009 * # N88-22851 * # N88-22446 * # N88-22033 * # N88-22050 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126	. p 526 . p 551 . p 499 . p 538	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173	p 551 p 548 p 498 p 525 p 526 p 551	N88-23226 * # N88-22382 * # N88-22019 * # N88-22037 * # N88-22902 * # N88-23220 * #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428	p 499 p 496 p 558 p 549 p 516 p 538	N88-22864 # # N88-22009 # # N88-22851 * # N88-22446 * # N88-22033 * # N88-22050 * # N88-22883 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426	. p 526 . p 551 . p 499 . p 538 . p 497	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * # N88-22013 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173 ESA-TT-1002	p 551 p 548 p 498 p 525 p 526 p 551	N88-23226 * # N88-22382 * # N88-22017 * # N88-22902 * # N88-23220 * # N88-2993 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529	p 499 p 496 p 558 p 549 p 538 p 506 p 497	N88-22864 # # N88-22009 # # N88-22851 * # N88-22446 * # N88-22033 * # N88-22050 * # N88-22016 * # N88-22016 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426	. p 526 . p 551 . p 499 . p 538 . p 497	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * # N88-22013 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173 ESA-TT-1002 ESA-TT-1075	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550	N88-23226 * # N88-22382 * # N88-22019 * # N88-22037 * # N88-22902 * # N88-23220 * # N88-23220 # N88-23161 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543	p 499 p 496 p 558 p 549 p 538 p 506 p 497 p 497	N88-22864 # N88-22009 * # N88-22051 * # N88-22851 * # N88-22033 * # N88-22050 * # N88-22016 * # N88-22015 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426 NASA-TP-2784 NASA-TP-2804	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547	N88-22902 * # N88-23220 * # N88-22662 * # N88-22047 * # N88-22013 * # N88-22710 * # N88-2325 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173 ESA-TT-1002	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550	N88-23226 * # N88-22382 * # N88-22019 * # N88-22037 * # N88-22902 * # N88-23220 * # N88-23220 # N88-23161 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544	p 499 p 496 p 558 p 549 p 538 p 538 p 506 p 497 p 499	N88-22864 # # N88-22009 * # N88-22851 * # N88-22851 * # N88-22466 * # N88-22050 * # N88-22016 * * * * * * * * * * * * * * * * * * *	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547	N88-22902 * # N88-23220 * # N88-22662 * # N88-22047 * # N88-22013 * # N88-22710 * # N88-2325 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173 ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 553	N88-23226 * # N88-22382 * # N88-22019 * # N88-22017 * # N88-22902 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100548	p 499 p 496 p 558 p 516 p 538 p 506 p 497 p 499 p 542	N88-22864 #  N88-22009 * #  N88-22051 * #  N88-22446 * #  N88-22030 * #  N88-22050 * #  N88-22016 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426 NASA-TP-2784 NASA-TP-2804 NASA-TP-2808	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516	N88-22902 * # N88-23220 * # N88-22662 * # N88-22047 * # N88-22013 * # N88-22710 * # N88-22325 * # N88-22031 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173 ESA-TT-1002 ESA-TT-1075 ESA-TT-1076	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 553	N88-23226 * # N88-22382 * # N88-22019 * # N88-22017 * # N88-22902 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569	p 499 p 496 p 558 p 516 p 538 p 506 p 497 p 498 p 542 p 517	N88-2209	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516	N88-22920 * # N88-23220 * # N88-22662 * # N88-22017 * # N88-22013 * # N88-22710 * # N88-22325 * # N88-22031 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173 ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094	p 551 p 548 p 498 p 525 p 526 p 551 p 550 p 550 p 550 p 553 p 517	N88-23226 * # N88-22382 * # N88-22019 * # N88-22019 * # N88-22902 * # N88-23220 * # N88-2320 * # N88-23161 # N88-23169 # N88-23346 # N88-23890 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100549 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569	p 499 p 496 p 558 p 549 p 516 p 538 p 506 p 497 p 497 p 499 p 542 p 548	N88-22864 #  N88-22009 * #  N88-22851 * #  N88-22446 * #  N88-22050 * #  Source	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-20209	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 539	N88-2902 * # N88-23220 * # N88-22662 * # N88-22013 * # N88-22710 * # N88-22325 * # N88-2231 * # N88-22326 * # N88-22911 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 553 p 517	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-2290 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-23346 # N88-23346 * #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100529 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100583	p 499 p 496 p 558 p 559 p 516 p 538 p 506 p 497 p 497 p 499 p 517 p 498 p 548 p 548	N88-22864 # N88-22009 * # N88-22051 * # N88-22851 * # N88-22013 * # N88-22050 * # N88-22050 * # N88-22016 * # N88-22016 * # N88-22016 * # N88-22063 * # N88-22063 * # N88-22863 * # N88-22863 * # N88-22863 * # N88-22863 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 539	N88-2902 * # N88-23220 * # N88-22662 * # N88-22013 * # N88-22710 * # N88-22325 * # N88-2231 * # N88-22326 * # N88-22911 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91474	p 551 p 548 p 498 p 525 p 526 p 551 p 550 p 550 p 553 p 517 p 547 p 476	N88-23226 * # N88-22382 * # N88-22019 * # N88-22019 * # N88-22902 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-23346 # N88-22890 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100588 NAS 1.15:100588 NAS 1.15:100588	p 499 p 496 p 558 p 558 p 516 p 538 p 506 p 497 p 497 p 492 p 542 p 547 p 558	N88-22864 # N88-22009 # N88-22009 # N88-22851 * # N88-22033 * # N88-22050 * # N88-22050 * # N88-22016 * # N88-22015 * # N88-22015 * # N88-22015 * # N88-22015 * # N88-22012 * # N88-22892 * # N88-22892 * # N88-22034 * # N88-22034 * # N88-22034 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-20209 NASA-TT-20251	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 539 . p 556	N88-22920 * # N88-23220 * # N88-22662 * # N88-22017 * # N88-22013 * # N88-22710 * # N88-22325 * # N88-22321 * # N88-22326 * # N88-2236 * # N88-22698 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91474 ETN-88-91566	p 551 p 548 p 498 p 525 p 526 p 551 p 550 p 550 p 553 p 517 p 547 p 476 p 476	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-2202 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-2326 * # N88-22855 N88-22855 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100549 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100588 NAS 1.15:100588 NAS 1.15:100589 NAS 1.15:100589 NAS 1.15:100589 NAS 1.15:100699	p 499 p 496 p 558 p 559 p 518 p 506 p 497 p 497 p 498 p 517 p 497 p 497 p 517 p 554	N88-22864 #  N88-2209	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-20209	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 539 . p 556	N88-22920 * # N88-23220 * # N88-22662 * # N88-22017 * # N88-22013 * # N88-22710 * # N88-22325 * # N88-22321 * # N88-22326 * # N88-2236 * # N88-22698 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1076 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91866 ETN-88-91866 ETN-88-91866	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 553 p 517 p 547 p 476 p 476 p 546	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-2202 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-23346 # N88-22856 * # N88-2285	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100588 NAS 1.15:100595 NAS 1.15:100609 NAS 1.15:100609 NAS 1.15:100612	p 499 p 496 p 558 p 518 p 506 p 497 p 497 p 497 p 497 p 517 p 558	N88-22864 #  N88-22009 * #  N88-22009 * #  N88-22051 * #  N88-2216 * #  N88-22050 * #  N88-22050 * #  N88-22050 * #  N88-22015 * #  N88-22015 * #  N88-22012 * #  N88-22843 * #  N88-22434 * #  N88-22434 * #  N88-22434 * #  N88-22437 * #  N88-23547 * #	NASA-TM-100891 NASA-TM-101918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TT-20161 NASA-TT-2029 NASA-TT-20251 NBSIR-87/3080	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 539 . p 556 . p 538	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * # N88-22013 * # N88-22710 * # N88-22326 * # N88-22326 * # N88-22911 * # N88-22948 * #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91566 ETN-88-91886 ETN-88-91886	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 550 p 557 p 547 p 476 p 476 p 546 p 543	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-2202 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-2236 * # N88-22855 N88-22856 # N88-2290 # N88-2290 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100588 NAS 1.15:100588 NAS 1.15:100595 NAS 1.15:100609 NAS 1.15:100609 NAS 1.15:100612 NAS 1.15:100612	p 499 p 496 p 549 p 558 p 516 p 538 p 506 p 497 p 497 p 497 p 497 p 558 p 557 p 557	N88-22064 # N88-22090 * # N88-22090 * # N88-22446 * # N88-22033 * # N88-22050 * # N88-22016 * # N88-22015 * # N88-22015 * # N88-22015 * # N88-22012 * # N88-22892 * # N88-22434 * # N88-22633 * # N88-23547 * # N88-23617 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 539 . p 556 . p 538 . p 538	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91474 ETN-88-91566 ETN-88-91886 ETN-88-91947 ETN-88-91947	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 553 p 517 p 476 p 476 p 543 p 543 p 529	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22320 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-23346 * # N88-2236 * # N88-2236 * # N88-2236 * # N88-22290 # N88-2298 # N88-22998 # N88-22998 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100548 NAS 1.15:100588 NAS 1.15:100589 NAS 1.15:100589 NAS 1.15:100699 NAS 1.15:100612 NAS 1.15:100612 NAS 1.15:100873 NAS 1.15:100887	p 499 p 496 p 548 p 558 p 558 p 508 p 508 p 508 p 508 p 508 p 549 p 497 p 498 p 542 p 557 p 557 p 548 p 558 p 5567 p 548	N88-22864 # N88-22009 * # N88-22091 * # N88-22851 * # N88-22466 * # N88-22050 * # N88-22050 * # N88-22050 * # N88-22051 * # N88-22015 * # N88-22017 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86046-U	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 539 . p 538 . p 538	N88-22902 * # N88-23220 * # N88-22662 * # N88-22017 * # N88-22013 * #  N88-22710 * # N88-22325 * # N88-22031 * #  N88-22326 * # N88-22698 * #  N88-22698 * #  N88-22088 #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1076 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91886 ETN-88-91886 ETN-88-91886 ETN-88-91977 ETN-88-91977	p 551 p 548 p 498 p 525 p 526 p 551 p 550 p 550 p 553 p 517 p 476 p 476 p 543 p 543 p 550 p 550	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-2290 * # N88-2320 * # N88-23161 # N88-23161 # N88-23346 # N88-2346 # N88-22856 * # N88-22856 * N88-2290 # N88-2290 # N88-2290 # N88-2290 # N88-2290 # N88-2290 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100588 NAS 1.15:100690 NAS 1.15:100609 NAS 1.15:100873 NAS 1.15:100873 NAS 1.15:100873 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887	p 499 p 496 p 548 p 558 p 538 p 508 p 509 p 497 p 497 p 497 p 548 p 557 p 557 p 558 p 558 p 558 p 558 p 558 p 558	N88-22864 #  N88-22851 * #  N88-22851 * #  N88-22851 * #  N88-22850 * #  N88-22050 * #  N88-22050 * #  N88-22015 * #  N88-22015 * #  N88-22015 * #  N88-22012 * #  N88-2283 * #  N88-2283 * #  N88-2283 * #  N88-2283 * #  N88-22892 * #  N88-22892 * #  N88-22892 * #  N88-22434 * #  N88-22434 * #  N88-22434 * #  N88-22434 * #  N88-22437 * #  N88-22436 * #  N88-22436 * #  N88-22637 * #  N88-22037 * #  N88-22037 * #  N88-22037 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TT-20161 NASA-TT-2029 NASA-TT-20251 NBSIR-87/3080  NLR-MP-86046-U NLR-MP-86045-U NLR-MP-86059-U	. p 526 . p 551 . p 497 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 556 . p 538 . p 528 . p 528 . p 5217 . p 547	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1094  ETN-87-98751 ETN-88-91474 ETN-88-91566 ETN-88-91886 ETN-88-91947 ETN-88-91947 ETN-88-91974 ETN-88-91977 ETN-88-91977	p 551 p 548 p 525 p 526 p 551 p 550 p 550 p 550 p 553 p 517 p 547 p 476 p 546 p 543 p 529 p 550 p 547 p 547	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-23220 * # N88-23220 * # N88-23161 # N88-23169 # N88-23366 # N88-22856 * # N88-22856 * # N88-2290 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100699 NAS 1.15:1006973 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100891 NAS 1.15:100891	p 499 p 496 p 548 p 558 p 558 p 538 p 538 p 497 p 497 p 497 p 497 p 554 p 555 p 552 p 555 p 552 p 555	N88-22864 # N88-22009 * N88-22009 * N88-22009 * N88-22851 * N88-22033 * N88-22050 * N88-22050 * N88-22016 * N88-22015 * N88-22015 * N88-22015 * N88-22012 * N88-22892 * N88-22892 * N88-22893 * N88-22693 * N88-22012 *	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86046-U	. p 526 . p 551 . p 497 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 556 . p 538 . p 528 . p 528 . p 5217 . p 547	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-88-91474 ETN-88-91566 ETN-88-91886 ETN-88-91886 ETN-88-91977 ETN-88-91977 ETN-88-92018 ETN-88-92018 ETN-88-92018	p 551 p 548 p 498 p 525 p 526 p 551 p 550 p 550 p 550 p 557 p 476 p 476 p 543 p 550 p 550 p 550 p 550 p 550 p 550 p 550 p 547 p 547 p 547 p 547 p 547 p 547 p 547 p 548 p 648 p 548 p 648 p 648	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-23220 * # N88-23161 # N88-23161 # N88-23169 # N88-23346 # N88-22326 * # N88-22890 # N88-2290 # N88-2290 # N88-22908 # N88-22909 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100548 NAS 1.15:100588 NAS 1.15:100588 NAS 1.15:100588 NAS 1.15:100699 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100891 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918	p 499 p 496 p 549 p 549 p 516 p 538 p 538 p 549 p 497 p 497 p 497 p 548 p 556 p 556 p 556 p 526 p 526 p 526 p 526 p 549	N88-22864 # N88-22009 # N88-22009 # N88-22851 * # N88-22851 * # N88-22050 * # S N88-22050 * # S N88-22050 * # S N88-22050 * # S N88-22015 * # S N88-22015 * # S N88-22015 * # S N88-22012 * # S N88-22853 * # S N88-22019 * # S N88-22019 * # S N88-22019 * # S N88-22019 * # S N88-22002 * # S N88-23020 * # S N88-23020 * # S N88-23020 * # S N88-22862 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U	. p 526 . p 559 . p 559 . p 538 . p 497 . p 556 . p 547 . p 539 . p 538 . p 538 . p 538 . p 538 . p 538 . p 547 . p 547 . p 547 . p 547 . p 547 . p 547	N88-22902 * # N88-23220 * # N88-22662 * # N88-22017 * # N88-22013 * # N88-22325 * # N88-22326 * # N88-22326 * # N88-22698 * # N88-22698 * # N88-22698 * # N88-22038 # N88-22038 # N88-22039 # N88-22039 # N88-22017 #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1076 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91566 ETN-88-91886 ETN-88-91886 ETN-88-91974 ETN-88-91974 ETN-88-91977 ETN-88-92018 ETN-88-92077 ETN-88-92074	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 550 p 557 p 547 p 547 p 546 p 543 p 549 p 550 p 550 p 550 p 550 p 550 p 551 p 547 p 547 p 547 p 547 p 547 p 547 p 547 p 548 p 548	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-2290 * # N88-2320 * # N88-23161 # N88-23169 # N88-23346 # N88-22306 * # N88-22856 * # N88-22856 * # N88-22903 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100568 NAS 1.15:100568 NAS 1.15:100690 NAS 1.15:100697 NAS 1.15:100873 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100981 NAS 1.15:100918	p 499 p 496 p 558 p 5516 p 558 p 549 p 497 p 497 p 548 p 554 p 555 p 555 p 556 p 556 p 557 p 498	N88-22864	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251 NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 539 . p 556 . p 538 . p 557 . p 517 . p 518	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1094  ETN-87-98751 ETN-88-91474 ETN-88-91566 ETN-88-91886 ETN-88-91947 ETN-88-91977 ETN-88-92018 ETN-88-92018 ETN-88-92076 ETN-88-92094 ETN-88-92094 ETN-88-92094	p 551 p 548 p 498 p 525 p 526 p 551 p 550 p 550 p 553 p 517 p 547 p 547 p 546 p 543 p 559 p 550 p 553 p 550 p 553 p 555 p 547 p 547 p 548 p 556 p 556 p 556 p 557	N88.23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-2320 * # N88-2320 * # N88-23161 # N88-23169 # N88-2336 * # N88-2285	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100697 NAS 1.15:100697 NAS 1.15:100697 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100891 NAS 1.15:100891 NAS 1.15:1009918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100926 NAS 1.15:100918 NAS 1.15:100926 NAS 1.15:100918 NAS 1.15:10022 NAS 1.15:4032 NAS 1.15:4032	p 499 p 496 p 549 p 556 p 506 p 506 p 497 p 497 p 497 p 497 p 556 p 557 p 496 p 557 p 496 p 557 p 496 p 558 p 557 p 496 p 557 p 496 p 558 p 558	N88-22064 #  N88-22009 #  N88-22090 * #  N88-22446 * #  N88-22033 * #  N88-22016 * #  N88-22012 * #  N88-22012 * #  N88-22012 * #  N88-23434 * #  N88-23434 * #  N88-23434 * #  N88-23434 * #  N88-22012 * #  N88-22012 * #  N88-22012 * #  N88-22012 * #  N88-22013 * #  N88-22003 * #  N88-22003 * #  N88-22004 * #  N88-22004 * #  N88-22001 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251 NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 539 . p 556 . p 538 . p 557 . p 517 . p 518	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-88-91846 ETN-88-91566 ETN-88-91866 ETN-88-9187 ETN-88-91947 ETN-88-91947 ETN-88-91977 ETN-88-92018 ETN-88-92018 ETN-88-92017 ETN-88-92017 ETN-88-92018 ETN-88-92019 ETN-88-92019	p 551 p 548 p 498 p 525 p 526 p 551 p 529 p 550 p 550 p 553 p 517 p 476 p 476 p 543 p 550 p 553 p 557 p 547 p 556 p 553 p 557 p 547 p 548 p 559 p 550 p 551 p 550 p 551 p 550 p 551 p 550 p 551 p 550 p 550	N88-23226 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-2203 * # N88-2320 * # N88-23161 # N88-23161 # N88-23169 # N88-2336 * # N88-22326 * # N88-22890 # N88-2290 # N88-22998 # N88-22903 # N88-22161 # N88-22113 # N88-22330 # N88-22330 # N88-22330 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100588 NAS 1.15:100699 NAS 1.15:1006973 NAS 1.15:100612 NAS 1.15:1006973 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100126 NAS 1.15:00918 NAS 1.15:00928 NAS 1.15:00928 NAS 1.15:00930	p 499 p 496 p 548 p 558 p 550 p 500 p 497 p 497 p 548 p 558	N88-22864	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 539 . p 556 . p 538 . p 557 . p 517 . p 518	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1076 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91566 ETN-88-91886 ETN-88-91886 ETN-88-91974 ETN-88-91974 ETN-88-91974 ETN-88-92018 ETN-88-92018 ETN-88-92076 ETN-88-92077 ETN-88-92094 ETN-88-92113 ETN-88-92199 ETN-88-92199	p 551 p 548 p 525 p 526 p 551 p 529 p 550 p 550	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22902 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-23346 # N88-22326 * # N88-22855   N88-22856 # N88-22903 # N88-22909 # N88-22909 # N88-22909 # N88-22909 # N88-22309 # N88-22309 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100072 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100688 NAS 1.15:100688 NAS 1.15:100695 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100918 NAS 1.15:10126 NAS 1.15:10126 NAS 1.15:10126 NAS 1.15:100918 NAS 1.15:10012 NAS 1.15:100918 NAS 1.15:10012 NAS 1.15:100918 NAS 1.15:10012 NAS 1.15:100918 NAS 1.15:4032 NAS 1.15:4032	p 499 p 496 p 549 p 556 p 556 p 506 p 497 p 497 p 542 p 542 p 542 p 546 p 497 p 557 p 497 p 556 p 557 p 498 p 557 p 558	N88-22864	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251 NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442  NTIA-87-228  NTSR-AAR-88-01-SUMM	. p 526 . p 551 . p 497 . p 556 . p 547 . p 556 . p 547 . p 516 . p 547 . p 538 . p 538 . p 528 . p 517 . p 517 . p 518 . p 518	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * # N88-22013 * # N88-2225 * # N88-2235 * # N88-2235 * # N88-2236 * # N88-22911 * # N88-2298 * # N88-22048 # N88-22048 # N88-22049 # N88-22894 # N88-22894 # N88-22894 #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1094  ETN-87-98751 ETN-88-91876 ETN-88-91876 ETN-88-91876 ETN-88-91977 ETN-88-91977 ETN-88-92077 ETN-88-92018 ETN-88-92018 ETN-88-92193 ETN-88-92223 ETN-88-92223	p 551 p 548 p 525 p 526 p 551 p 550 p 550	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-2320 * # N88-23361 # N88-23161 # N88-23161 # N88-23366 * # N88-22856 * # N88-22856 * # N88-22856 # N88-2290 # N88-2230 # N88-2230 # N88-22330 # N88-22330 # N88-22330 # N88-22330 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100588 NAS 1.15:100588 NAS 1.15:100697 NAS 1.15:100612 NAS 1.15:100873 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100891 NAS 1.15:100891 NAS 1.15:100991 NAS 1.15:100918 NAS 1.15:1032 NAS 1.15:4032 NAS 1.15:4032 NAS 1.15:4032 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-1	p 499 p 499 p 558 p 558 p 558 p 506 p 507 p 499 p 517 p 518 p 558 p 558 p 558 p 558 p 499 p 558 p 499 p 558 p 499 p 558 p 499 p 558	N88-22864 * #  N88-22009 * #  N88-22009 * #  N88-22851 * #  N88-22033 * #  N88-22016 * #  N88-22016 * #  N88-22016 * #  N88-22015 * #  N88-22015 * #  N88-22016 * #  N88-22016 * #  N88-22016 * #  N88-22019 * #  N88-22012 * #  N88-22012 * #  N88-2363 * #  N88-2363 * #  N88-2363 * #  N88-22012 * #  N88-22012 * #  N88-22013 * #  N88-22019 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251 NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442  NTIA-87-228  NTSR-AAR-88-01-SUMM	. p 526 . p 551 . p 497 . p 556 . p 547 . p 556 . p 547 . p 516 . p 547 . p 538 . p 538 . p 528 . p 517 . p 517 . p 518 . p 518	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * # N88-22013 * # N88-2225 * # N88-2235 * # N88-2235 * # N88-2236 * # N88-22911 * # N88-2298 * # N88-22048 # N88-22048 # N88-22049 # N88-22894 # N88-22894 # N88-22894 #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1094  ETN-87-98751 ETN-88-91474 ETN-88-91886 ETN-88-91896 ETN-88-91947 ETN-88-92018 ETN-88-92018 ETN-88-92018 ETN-88-92019 ETN-88-92019 ETN-88-92113 ETN-88-92223 ETN-88-92223 ETN-88-92225 ETN-88-92225	p 551 p 548 p 525 p 526 p 526 p 550 p 550 p 550 p 550 p 550 p 550 p 570 p 570	N88-23226 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-22902 * # N88-23220 * # N88-23161 # N88-23169 # N88-23366 * # N88-22326 * # N88-22855 * # N88-22856 # N88-22998 # N88-22999 # N88-22999 # N88-22909 # N88-22330 # N88-22330 # N88-22330 # N88-22330 # N88-22311 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100072 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100428 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100543 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:10069 NAS 1.15:10069 NAS 1.15:100698 NAS 1.15:100698 NAS 1.15:100691 NAS 1.15:100612 NAS 1.15:1008173 NAS 1.15:1008173 NAS 1.15:1008173 NAS 1.15:1008173 NAS 1.15:1008173 NAS 1.15:1008173 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:89426 NAS 1.26:177330 NAS 1.26:177333-VOL-1 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-2	p 4996 p 4996 p 5586 p 5596 p 5066 p 4976 p 5066 p 4976 p 54976 p 54976 p 5576	N88-22864	NASA-TM-100891 NASA-TM-101918 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2804 NASA-TP-2808 NASA-TT-20161 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86046-U NLR-MP-86059-U NLR-MP-86074-U  NRC-28442  NTIA-87-228	. p 526 . p 551 . p 497 . p 556 . p 547 . p 556 . p 547 . p 516 . p 547 . p 538 . p 538 . p 528 . p 517 . p 517 . p 518 . p 518	N88-22902 * # N88-23220 * # N88-22862 * # N88-22047 * # N88-22013 * # N88-2225 * # N88-2235 * # N88-2235 * # N88-2236 * # N88-22911 * # N88-2298 * # N88-22048 # N88-22048 # N88-22049 # N88-22894 # N88-22894 # N88-22894 #
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1094  ETN-88-91474 ETN-88-91566 ETN-88-91886 ETN-88-91886 ETN-88-91977 ETN-88-91977 ETN-88-91977 ETN-88-92018 ETN-88-92025 ETN-88-92225 ETN-88-92225	P 551 P 548 P 525 P 526 P 551 P 550 P 550 P 550 P 550 P 570 P 540 P 540 P 540 P 540 P 540 P 550 P 570 P 570	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-2220 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-22326 * # N88-22855 * # N88-22856 # N88-22856 # N88-2298 # N88-22998 # N88-22998 # N88-22999 # N88-22903 # N88-22903 # N88-22909 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100688 NAS 1.15:100698 NAS 1.15:100698 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100818 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:4032 NAS 1.15:4032 NAS 1.15:4032 NAS 1.26:177330 NAS 1.26:177333-VOL-1 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-2 NAS 1.26:177343-VOL-4 NAS 1.26:177343-VOL-4	p 499 p 496 p 549 p 556 p 506 p 507 p 497 p 549 p 549 p 549 p 549 p 549 p 542 p 557 p 497 p 558	N88-22864	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TT-20161 NASA-TT-20259 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86046-U NLR-MP-86059-U NLR-MP-86074-U  NRC-28442  NTIA-87-228  NTSB-AAR-88-01-SUMM NTSB-AAR-88-01	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 547 . p 539 . p 538 . p 518 . p 518 . p 518 . p 538 . p 538 . p 538	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1094  ETN-88-91866 ETN-88-91876 ETN-88-91876 ETN-88-91977 ETN-88-91974 ETN-88-91977 ETN-88-92077 ETN-88-92018 ETN-88-92018 ETN-88-9219 ETN-88-92199 ETN-88-92225 ETN-88-92274 ETN-88-92275 ETN-88-92275 ETN-88-92310	p 551 p 548 p 525 p 526 p 551 p 552 p 550 p 550 p 553 p 517 p 547 p 547 p 546 p 543 p 550 p 551 p 547 p 547	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-2290 * # N88-23161 # N88-23161 # N88-23166 # N88-2336 * # N88-22856 * # N88-22856 * # N88-22856 # N88-2290 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100588 NAS 1.15:100588 NAS 1.15:100697 NAS 1.15:100612 NAS 1.15:100873 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100891 NAS 1.15:100918 NAS 1.15:1032 NAS 1.15:4032 NAS 1.15:4032 NAS 1.15:4032 NAS 1.15:4034 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-4 NAS 1.26:177343-VOL-4 NAS 1.26:177343-VOL-4 NAS 1.26:177355 NAS 1.26:181641	p 499 p 496 p 558 p 558 p 556 p 556 p 506 p 497 p 492 p 517 p 557 p 492 p 557 p 457 p 558 p 497 p 558 p 497 p 558 p 497 p 558	N88-22864 * #  N88-22864 * #  N88-22090 * #  N88-22851 * #  N88-22033 * #  N88-22016 * #  N88-22016 * #  N88-22016 * #  N88-22015 * #  N88-22015 * #  N88-22015 * #  N88-22016 * #  N88-22016 * #  N88-22016 * #  N88-22016 * #  N88-22017 * #  N88-22012 * #  N88-22653 * #  N88-23654 * #  N88-23654 * #  N88-23019 * #  N88-22019 * #  N88-23019 * #  N88-23019 * #  N88-23019 * #  N88-23019 * #	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251 NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442  NTIA-87-228  NTSR-AAR-88-01-SUMM	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 547 . p 539 . p 538 . p 518 . p 518 . p 518 . p 538 . p 538 . p 538	N88-22902
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E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1094  ETN-88-9184 ETN-88-9186 ETN-88-9186 ETN-88-9197 ETN-88-9197 ETN-88-92018 ETN-88-9207 ETN-88-92018 ETN-88-9213 ETN-88-92275 ETN-88-92310 ETN-88-92461	p 551 p 548 p 525 p 526 p 526 p 550 p 550 p 550 p 550 p 550 p 550 p 570 p 570	N88-23266 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-22902 * # N88-2320 * # N88-23161 # N88-23161 # N88-23169 # N88-23366 * # N88-22866 * # N88-22866 # N88-22998 # N88-22999 # N88-22999 # N88-22999 # N88-22999 # N88-22909 # N88-2281 # N88-2281 # N88-22860 # N88-22860 # N88-22888 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100072 NAS 1.15:100172 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100583 NAS 1.15:100583 NAS 1.15:100612 NAS 1.15:100612 NAS 1.15:100612 NAS 1.15:100813 NAS 1.15:100813 NAS 1.15:100813 NAS 1.15:100814 NAS 1.15:100814 NAS 1.15:100815 NAS 1.15:100815 NAS 1.15:100816 NAS 1.15:100816 NAS 1.15:100817 NAS 1.15:100818 NAS 1.15:100186 NAS 1.15:103186 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-2 NAS 1.26:181662 NAS 1.26:181662 NAS 1.26:181665 NAS 1.26:181665 NAS 1.26:181665 NAS 1.26:181665 NAS 1.26:181665 NAS 1.26:181665	p 499 p 499 p 558 p 558 p 506 p 497 p 497 p 497 p 497 p 497 p 558	N88-22094	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TT-20161 NASA-TT-20209 NASA-TT-20251 NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442  NTIA-87-228  NTSB-AAR-88-01-SUMM NTSB-AAR-88-01  NTSB/AAB-87/12  NTSB/AAB-87/12  NTSB/AAR-87/09 PB87-910412	. p 526 . p 551 . p 499 . p 538 . p 497 . p 556 . p 547 . p 516 . p 547 . p 539 . p 558 . p 517 . p 518 . p 518 . p 518 . p 518 . p 502 . p 502 . p 502	N88-22902
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E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1075 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91474 ETN-88-91566 ETN-88-91886 ETN-88-91947 ETN-88-91977 ETN-88-9219 ETN-88-92018 ETN-88-92018 ETN-88-9217 ETN-88-9219 ETN-88-9219 ETN-88-9219 ETN-88-92274 ETN-88-92274 ETN-88-92275 ETN-88-92310 ETN-88-92310 ETN-88-92317 ETN-88-92323 ETN-88-92323 ETN-88-92323 ETN-88-92461 ETN-88-92466 ETN-88-92558 ETN-88-92558	P 551 P 526 P 552 P 552 P 552 P 553 P 553 P 557 P 547	N88-23226 * # N88-22319 * # N88-22019 * # N88-22019 * # N88-22903 * # N88-23220 * # N88-23346 # N88-23346 # N88-23346 # N88-2290 # N88-22856 # N88-22856 # N88-2290 # N88-2289 # N88-2289 # N88-2289 # N88-2890 # N88-2890 # N88-2890 # N88-2890 # N88-2890 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100077 NAS 1.15:100279 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100583 NAS 1.15:100612 NAS 1.15:100891 NAS 1.15:100895 NAS 1.15:100891 NAS 1.15:100873 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:1091887 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-1 NAS 1.26:181664 NAS 1.26:181665 NAS 1.26:181665 NAS 1.26:182877 NAS 1.26:182877 NAS 1.26:182877 NAS 1.26:182879 NAS 1.26:182899	p 499 p 499 p 558 p 558 p 506 p 497 p 497 p 497 p 497 p 497 p 497 p 558 p 559	N88-22064	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TT-20161 NASA-TT-2029 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442  NTIA-87-228  NTSB-AAR-88-01-SUMM NTSB-AAR-88-01 NTSB/AAB-87/12  NTSB/AAB-87/09  PB87-910412 PB87-916912 PB88-149885 PB8-169055	. p 526 . p 551 . p 497 . p 556 . p 557 . p 557 . p 558 . p 538 . p 538 . p 538 . p 538 . p 538 . p 538 . p 502 . p 503	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1076 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91566 ETN-88-91566 ETN-88-91886 ETN-88-91974 ETN-88-91974 ETN-88-91974 ETN-88-91974 ETN-88-91974 ETN-88-91975 ETN-88-92074 ETN-88-9210 ETN-88-9210 ETN-88-9210 ETN-88-9225 ETN-88-9225 ETN-88-92274 ETN-88-92275 ETN-88-92310 ETN-88-92361 ETN-88-92561 ETN-88-92561 ETN-88-92561 ETN-88-92561	P 551 P 548 P 525 P 526 P 550 P 550	N88-23266 * # N88-22319 * # N88-22319 * # N88-22201 * # N88-22201 * # N88-22320 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-22326 * # N88-22855 * # N88-22856 # N88-22998 # N88-22998 # N88-22999 # N88-22990 # N88-22900 # N88-22901 # N88-22900 # N88-22860 # N88-23860 # N88-23860 # N88-23800 # N88-23800 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100077 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100583 NAS 1.15:10069 NAS 1.15:100887 NAS 1.15:100873 NAS 1.15:100873 NAS 1.15:100887 NAS 1.15:100891 NAS 1.15:100891 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:4032 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-1 NAS 1.26:181661 NAS 1.26:181662 NAS 1.26:181662 NAS 1.26:181665 NAS 1.26:182896 NAS 1.26:182897 NAS 1.26:182897 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896	p 499 p 498 p 558 p 558 p 506 p 497 p 549 p 506 p 497 p 498 p 549 p 557 p 557 p 557 p 558 p 558 p 559 p 557 p 558 p 558 p 558 p 558 p 559 p 549 p 559 p 559 p 559 p 559 p 549 p 559 p 559 p 559 p 549	N88-22864	NASA-TM-100891 NASA-TM-101126 NASA-TM-101126 NASA-TM-101126 NASA-TM-89426 NASA-TM-89426 NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TP-2808 NASA-TT-20161 NASA-TT-20259 NASA-TT-20251 NBSIR-87/3080 NLR-MP-86034-U NLR-MP-86046-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442 NTIA-87-228 NTSB-AAR-88-01-SUMM NTSB-AAR-88-01 NTSB/AAR-87/09 PB87-910412 PB87-910412 PB88-166095 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-190401	. p 526 . p 551 . p 497 . p 556 . p 557 . p 557 . p 558 . p 538 . p 538 . p 538 . p 538 . p 538 . p 538 . p 502 . p 503	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1076 ESA-TT-1076 ESA-TT-1080 ESA-TT-1080 ESA-TT-1084  ETN-88-91866 ETN-88-91866 ETN-88-91866 ETN-88-91869 ETN-88-9187 ETN-88-9187 ETN-88-9187 ETN-88-9187 ETN-88-9188 ETN-88-9188 ETN-88-9188 ETN-88-9207 ETN-88-9213 ETN-88-92018 ETN-88-92018 ETN-88-9210 ETN-88-9210 ETN-88-92113 ETN-88-92113 ETN-88-9215 ETN-88-9210 ETN-88-92561 ETN-88-92561	P 551 P 548 P 525 P 526 P 550 P 550	N88-23266 * # N88-22319 * # N88-22319 * # N88-22201 * # N88-22201 * # N88-22320 * # N88-23220 * # N88-23161 # N88-23169 # N88-23346 # N88-22326 * # N88-22855 * # N88-22856 # N88-22998 # N88-22998 # N88-22999 # N88-22990 # N88-22900 # N88-22901 # N88-22900 # N88-22860 # N88-23860 # N88-23860 # N88-23800 # N88-23800 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100077 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100549 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100548 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100583 NAS 1.15:100612 NAS 1.15:100612 NAS 1.15:100891 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100887 NAS 1.15:100810 NAS 1.15:100810 NAS 1.15:100810 NAS 1.15:100810 NAS 1.15:100918 NAS 1.26:177393 NAS 1.26:18739 NAS 1.26:181664 NAS 1.26:1816879 NAS 1.26:182892 NAS 1.26:182892 NAS 1.26:182892 NAS 1.26:182896 NAS 1.26:1428 NAS 1.26:4128 NAS 1.26:4128 NAS 1.26:4128 NAS 1.26:4128	p 499 p 496 p 549 p 556 p 506 p 497 p 549 p 549 p 549 p 549 p 549 p 557 p 497 p 557 p 498 p 557 p 498 p 557 p 557 p 558 p 558 p 558 p 558 p 559	N88-22864	NASA-TM-100891 NASA-TM-100918 NASA-TM-101126 NASA-TM-101126 NASA-TM-4032 NASA-TM-89426  NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TP-2808  NASA-TT-20161 NASA-TT-2029 NASA-TT-20251  NBSIR-87/3080  NLR-MP-86034-U NLR-MP-86059-U NLR-MP-86059-U NLR-MP-86074-U  NRC-28442  NTIA-87-228  NTSB-AAR-88-01-SUMM NTSB-AAR-88-01 NTSB/AAR-87/12  NTSB/AAR-87/09  PB87-910412 PB87-916912 PB88-166095 PB88-166095 PB88-166095	. p 526 . p 551 . p 497 . p 556 . p 557 . p 557 . p 558 . p 538 . p 538 . p 538 . p 538 . p 538 . p 538 . p 502 . p 503	N88-22902
E-3920 E-3970-VOL-1 E-3970-VOL-2 E-4099 E-4120 E-4129 E-4173  ESA-TT-1002 ESA-TT-1076 ESA-TT-1076 ESA-TT-1080 ESA-TT-1094  ETN-87-98751 ETN-88-91566 ETN-88-91566 ETN-88-91886 ETN-88-91974 ETN-88-91974 ETN-88-91974 ETN-88-91974 ETN-88-91974 ETN-88-91975 ETN-88-92074 ETN-88-9210 ETN-88-9210 ETN-88-9210 ETN-88-9225 ETN-88-9225 ETN-88-92274 ETN-88-92275 ETN-88-92310 ETN-88-92361 ETN-88-92561 ETN-88-92561 ETN-88-92561 ETN-88-92561	p 551 p 548 p 525 p 526 p 550 p 550	N88-23266 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-22019 * # N88-22020 * # N88-2320 * # N88-23161 # N88-23169 # N88-23366 * # N88-22326 * # N88-22998 # N88-22999 # N88-22899 # N88-22899 # N88-22899 # N88-22890 #	NAS 1.15:100090 NAS 1.15:100095 NAS 1.15:100077 NAS 1.15:100172 NAS 1.15:100415 NAS 1.15:100424 NAS 1.15:100424 NAS 1.15:100428 NAS 1.15:100529 NAS 1.15:100543 NAS 1.15:100543 NAS 1.15:100544 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100569 NAS 1.15:100583 NAS 1.15:100583 NAS 1.15:10069 NAS 1.15:100887 NAS 1.15:100873 NAS 1.15:100873 NAS 1.15:100887 NAS 1.15:100891 NAS 1.15:100891 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:100918 NAS 1.15:4032 NAS 1.26:177343-VOL-1 NAS 1.26:177343-VOL-1 NAS 1.26:181661 NAS 1.26:181662 NAS 1.26:181662 NAS 1.26:181665 NAS 1.26:182896 NAS 1.26:182897 NAS 1.26:182897 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896 NAS 1.26:182896	p 499 p 499 p 558 p 558 p 506 p 497 p 497 p 498 p 558 p 497 p 497 p 558 p 559	N88-22064	NASA-TM-100891 NASA-TM-101126 NASA-TM-101126 NASA-TM-101126 NASA-TM-89426 NASA-TM-89426 NASA-TP-2784 NASA-TP-2804 NASA-TP-2808 NASA-TP-2808 NASA-TT-20161 NASA-TT-20259 NASA-TT-20251 NBSIR-87/3080 NLR-MP-86034-U NLR-MP-86046-U NLR-MP-86059-U NLR-MP-86074-U NRC-28442 NTIA-87-228 NTSB-AAR-88-01-SUMM NTSB-AAR-88-01 NTSB/AAR-87/09 PB87-910412 PB87-910412 PB88-166095 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-178827 PB88-190401	. p 526 . p 551 . p 499 . p 538 . p 547 . p 556 . p 547 . p 556 . p 538 . p 517 . p 538 . p 517 . p 498 . p 518 . p 502 . p 503 . p 50	N88-22902

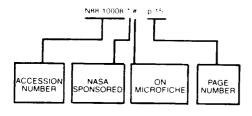
			538 538		# #
SAE P-203		. [	473	A88-37176	
SAE PAPER 871757 SAE PAPER 871859				A88-38775 * A88-38925 *	
SAE PAPER 871861		. [		A88-38950 *	
SAE PAPER 872305	***************************************	.	477	A88-37177	
SAE PAPER 872306		. [	477	A88-37178	
SAE PAPER 872307			477	A88-37179 *	
SAE PAPER 872308			477	A88-37180	
SAE PAPER 872309			477	A88-37181	
SAE PAPER 872310			530	A88-37182	
SAE PAPER 872311					
SAE PAPER 872312			479	A88-37235 *	
			507	A88-37183	
SAE PAPER 872313	***************************************		507	A88-37184	
SAE PAPER 872314			507	A88-37185	
SAE PAPER 872315	***************************************	F	508		#
SAE PAPER 872316			508	A88-37187 *	
SAE PAPER 872317		F	508	A88-37188	
<b>SAE PAPER 872319</b>		r	508	A88-37189	
SAE PAPER 872321			508	A88-37190	
SAE PAPER 872322			522	A88-37191	
SAE PAPER 872323			522	A88-37192	
SAE PAPER 872324			522	A88-37193	
SAE PAPER 872325			477		
SAE PAPER 872326				A88-37194	
			478	A88-37195	
SAE PAPER 872327			522	A88-37196	
SAE PAPER 872328			530	A88-37197 *	
SAE PAPER 872329		p	526	A88-37198 *	
SAE PAPER 872330		р	522	A88-37199 *	
SAE PAPER 872331		р	526	A88-37200	
<b>SAE PAPER 872332</b>			527	A88-37201	
SAE PAPER 872333	***************************************		508	A88-37202	
SAE PAPER 872334			527	A88-37203	
SAE PAPER 872335	•••••				
	••••••		508	A88-37204	
SAE PAPER 872337 SAE PAPER 872338			473	A88-37205	
			473	A88-37206	
SAE PAPER 872341			479	A88-37236 *	
SAE PAPER 872343			478	A88-37209 *	
SAE PAPER 872344		р	478	A88-37210 *	
SAE PAPER 872345		р	478	A88-37211	
SAE PAPER 872346		р	478	A88-37212	
SAE PAPER 872347		p	522	A88-37213	
SAE PAPER 872348			523	A88-37237 *	
SAE PAPER 872349			522	A88-37214	
SAE PAPER 872352			523	A88-37215 *	
SAE PAPER 872355			523	A88-37217 *	
SAE PAPER 872356			509	A88-37218	
SAE PAPER 872358			554	A88-37219 *	
SAE PAPER 872359	***************************************				
			478	A88-37220 *	
SAE PAPER 872360			555	A88-37221 *	
SAE PAPER 872361			479	A88-37222 *	
SAE PAPER 872362	••••••		509	A88-37223	
SAE PAPER 872365			473	A88-37238 *	
SAE PAPER 872370		þ	509	A88-37224	
SAE PAPER 872371		р	479	A88-37225 *	
SAE PAPER 872372		р	501	A88-37226 *	
SAE PAPER 872376		p	501	A88-37227	
SAE PAPER 872378			523	A88-37228	
0.E D.DED	***************************************		509	A88-37229	
SAE PAPER 872381			509	A88-37230	
SAE PAPER 872382		n	500	A88-37231	
SAE PAPER 872383	***************************************	'n	510	A88-37232	
SAE PAPER 872385		r	510	A88-37234 *	
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SER-510248		p	557	N88-23548 * #	ŧ
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SPIE-778		p	520	A88-41361	
TR-378		n	507	N88-22886 * #	ŧ
U-1541-349-PT-2				N88-23545 * #	
UDR-TR-87-91					
UILU-ENG-88-4001					
				N88-22320 #	
USAAVSCOM-TM-88- USAAVSCOM-TM-88-	B-009	p	542	N88-22905 * # N88-22949 * #	
USAFOEHL-87-164EH	10441LNA	p	556	N88-22702 #	
VA-87-001		p	521	N88-22900 #	

## **ACCESSION NUMBER INDEX**

### AERONAUTICAL ENGINEERING / A Continuing Bibliography (Supplement 230)

September 1988

#### **Typical Accession Number** Index Listing



Listings is this index are arranged alpha-numerically by accession number. The page number listed to the right indicates the page on which the citation is located. An asterisk (\*) indicates that the item is a NASA report. A pound sign (#) indicates that the item is available on microfiche.

A88-37108 *	- 540	400.0700	
	p 543	A88-37231	p 509
A88-37110	p 543	A88-37232	p 510
A88-37112	p 477	A88-37234 *	p 510
A88-37176	p 473	A88-37235 *	p 479
A88-37177	p 477	A88-37236 *	p 479
A88-37178	p 477	A88-37237 *	p 523
A88-37179 *	p 477	A88-37238 *	p 473
A88-37180	p 477	A88-37297 #	p 473
A88-37181	p 477	A88-37298 #	p 531
A88-37182	p 530	A88-37351	p 544
A88-37183	p 507	A88-37353 *	p 479
A88-37184		A88-37355 *	p 479
A88-37185	p 507	A88-37356	p 480
A88-37186 * #	p 507	A88-37358	p 480
A88-37186 * #	p 508	A88-37360	p 480
	p 508	A88-37376	p 502
A88-37188	p 508	A88-37377 #	p 502
A88-37189	p 508	A88-37378 #	p 503
A88-37190	p 508	A88-37379 #	p 503
A88-37191	p 522	A88-37385 #	p 503
A88-37192	p 522	A88-37386 #	p 503
A88-37193	p 522	A88-37390 #	p 503
A88-37194	p 477	A88-37393 #	p 503
A88-37195	p 478	A88-37394 #	p 503
A88-37196	p 522	A88-37397 * #	p 503
A88-37197 *	p 530	A88-37399 #	p 504
A88-37198 *	p 526	A88-37400 #	p 504
A88-37199 *	p 522	A88-37402 #	p 504
A88-37200	p 526	A88-37403 #	p 504
A88-37201	p 527	A88-37404 #	p 504
A88-37202	p 508	A88-37405 #	p 504
A88-37203	p 527	A88-37406 #	p 505
A88-37204	p 508	A88-37412 #	p 505
A88-37205	p 473	A88-37429 #	p 540
A88-37206	p 473	A88-37430 #	p 540
A88-37209 *	p 478	A88-37543	p 523
A88-37210 *	p 478	A88-37549	p 544
A88-37211	p 478	A88-37653	p 480
A88-37212	p 478	A88-37657	p 480
A88-37213	p 522	A88-37661	p 544
A88-37214	p 522	A88-37665	p 480
A88-37215 *	p 523	A88-37697	p 480
A88-37217 *	p 523	A88-37699	p 505
A88-37218	p 509	A88-37703	p 510
A88-37219 *	p 554	A88-37907	p 531
A88-37220 *	p 478		
A88-37221 *	p 555		p 531
A88-37222 *	p 479		p 531
A88-37223	p 509	A88-37911 * #	p 531
A88-37224	p 509	A88-37912 #	p 531
A88-37225 *	p 479	A88-37913 #	p 531
A88-37226 *	p 501	A88-37914 #	p 531
A88-37227	p 501	A88-37915 #	p 532
A88-37228	p 523	A88-37916 #	p 532
A88-37229	p 509	A88-37917 * #	p 532
A88-37230	p 509		
. 100-01 200	h 202	A88-37918 * #	p 532

A88-37919 * # A88-37920 * # A88-37920 * # A88-37921 # A88-37921 * # A88-37930 * # A88-37931 # A88-37930 * # A88-37941 # A88-37940 # A88-37940 # A88-37940 * # A88-37940 * # A88-37940 * # A88-38160 # A88-38116 A88-38167 A88-38167 A88-38179 # A88-38185 # A88-38185 # A88-38185 # A88-38185 # A88-38185 # A88-38187 # A88-38192 # A88-38393 # A88-38393 # A88-38390 # A88-38701 # A88-38700 # A88-38710 # A88-38711 #	P 532 P 533 P 533 P 533 P 544 P 548 P 548 P 548 P 533 P 534 P 534 P 534 P 534 P 535 P 534 P 535 P 544 P 548 P 548
A88-38705 # A88-38707 # A88-38710 # A88-38711 # A88-38713 # A88-38714 # A88-38715 # A88-38719 # A88-38720 # A88-38722 # A88-38722 # A88-38723 # A88-38726 #	p 505 p 518 p 511 p 473 p 535 p 535 p 536 p 505 p 519
A88-38727 # A88-38728 # A88-38729 # A88-38730 # A88-38731 * # A88-38736 # A88-38736 # A88-38737 * # A88-38738 * # A88-38740 #	p 511 p 512 p 512 p 512 p 512 p 512 p 512 p 512 p 512 p 527 p 527 p 536

A88-38744 #
A88-40327 p 545 A88-40375 # p 486 A88-40386 p 474 A88-40421 # p 486
A88-40386 p 474 A88-40421 # p 486
A88-40486 p 541

#### A88-40768

A88-40/68			
A88-40768 #	p 494	N88-22427 * #	p 542
A88-40771 #	p 495		p 548
A88-40858 #	p 528	N88-22431 * #	p 526
A88-40868 #	p 514		p 548
A88-40871 # A88-40970	p 546 p 495		p 549
A88-40972	p 495		р 552 р 554
A88-41048 #	p 495		p 556
A88-41089	p 506		p 556
A88-41092 #	p 495	N88-22706 #	p 556
A88-41096 A88-41098	p 520 p 520	N88-22710 * #	p 556
A88-41219	p 546	N88-22713 # N88-22821 #	p 556 p 557
A88-41222	p 515	N88-22851 *#	p 558
A88-41250	p 515	N88-22853 * #	p 558
A88-41269 A88-41270 *	p 495 p 495	N88-22855	p 476
A88-41288 *	p 540	N88-22856 #	p 476
A88-41361	p 520	N88-22859 # N88-22860 #	p 498 p 499
A88-41364	p 515	N88-22861 #	p 499
A88-41366	p 520	N88-22862 * #	p 499
A88-41367 A88-41368	p 520 p 520	N88-22863 * #	p 499
A88-41369	p 520	N88-22864 * #	p 499 p 499
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	<b>F</b>	N88-22865 * # N88-22866 * #	p 500
N88-22003 #	p 476	N88-22867 * #	p 500
N88-22004 #	p 495	N88-22868 * #	p 500
N88-22005 # N88-22006 #	p 496 p 496	N88-22869 #	p 500
N88-22007 #	p 496	N88-22870 # N88-22874 #	p 500 p 501
N88-22008 #	p 496	N88-22875 #	p 501
N88-22009 * #	p 496	N88-22876 #	p 502
N88-22010 *#	p 497 p 497	N88-22877 #	p 502
N88-22011 * # N88-22012 * #	p 497	N88-22878 #	p 502
N88-22013 * #	p 497	N88-22883 * # N88-22884 * #	p 506 p 507
N88-22014 * #	p 497	N88-22886 * #	p 507
N88-22015 * #	p 497	N88-22887 #	p 517
N88-22016 *#	р 497 р 498	N88-22888 #	p 517
N88-22017 # N88-22018 * #	p 498	N88-22889 # N88-22890 #	p 517 p 517
N88-22019 *#	p 498	N88-22891 * #	p 517
N88-22020 #	p 502	N88-22892 * #	p 517
N88-22021 # N88-22022 #	p 502 p 515	N88-22893 * #	p 518
N88-22022 # N88-22023 #	p 515	N88-22894 # '	p 518
N88-22024 #	p 515	N88-22895 # N88-22896 #	p 518 p 521
N88-22025 #	p 515	N88-22897 #	p 521
N88-22029 #	p 516	N88-22898 #	p 521
N88-22030 # N88-22031 * #	р 516 р 516	N88-22899 #	p 521
N88-22032 #	p 516	N88-22900 # N88-22901 * #	p 521 p 521
N88-22033 * #	p 516	N88-22902 * #	p 526
N88-22034 #	p 524	N88-22903 #	p 529
N88-22035 # N88-22036 #	p 524 p 525	N88-22904 * #	p 529
N88-22037 *#	p 525	N88-22905 * #	р 529 р 530
N88-22038 #	p 528	N88-22906 # N88-22907 #	p 538
N88-22039 #	p 528	N88-22909 #	p 539
N88-22040 #	p 529	N88-22911 * #	p 539
N88-22041 # N88-22042 #	p 529 p 529	N88-22912 #	p 539
N88-22043 #	p 537	N88-22940 # N88-22949 * #	p 542
N88-22044 #	p 537	N88-22954 #	p 542 p 542
N88-22045 * #	p 537	N88-22989	p 542
N88-22046 # N88-22047 * #	p 538 p 538	N88-22990	p 543
N88-22048 #	p 538	N88-22998 #	p 543 p 543
N88-22049 #	p 538	N88-23009 # N88-23011 #	p 543
N88-22050 * #	p 538	N88-23031 #	p 518
N88-22092 # N88-22115 #	p 541 p 541	N88-23126 * #	p 539
N88-22115 # N88-22121 #	p 541	N88-23127 * #	p 549
N88-22241 #	p 498	N88-23128 # N88-23129 #	р 539 р 518
N88-22243 #		N88-23130 #	p 549
N88-22244 #		N88-23132 #	p 539
N88-22245 # N88-22276 #		N88-23134 #	p 549
N88-22290 #		N88-23135 #	p 549
N88-22300 #	p 546	N88-23137 # N88-23138 #	р 549 р 549
N88-22305 #	p 547	N88-23139 #	p 550
N88-22320 #		N88-23152 #	p 550
N88-22325 * # N88-22326 * #		N88-23155 #	p 550
N88-22330 #		N88-23160 * # N88-23161 #	р 550 р 550
N88-22369 #	p 547	N88-23169 #	
N88-22382 * #		N88-23171 * #	p 551
N88-22383 * #		N88-23220 * #	p 551
N88-22384 * # N88-22390 * #		N88-23226 * #	p 551
N88-22393 * #	p 548	N88-23229 * # N88-23230 * #	
N88-22394 * #	p 525	N88-23230 # N88-23244 * #	
N88-22399 * #		N88-23245 * #	p 501
N88-22405 * #		N88-23246 * #	p 501
N88-22418 * #		N88-23247 * #	
N88-22426 * #	p 548	N88-23248 * #	p 501

N88-23249 \*# p 530
N88-23250 \*# p 530
N88-23253 \*# p 551
N88-23254 \*# p 551
N88-23256 \*# p 552
N88-23256 \*# p 552
N88-23463 \*# p 554
N88-23472 \*# p 554
N88-23519 \*# p 554
N88-23519 \*# p 556
N88-23548 \*# p 557

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